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A comparison of storm hydrographs from small urban watersheds with different land use patterns in Baton Rouge

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A COMPARISON OF STORM HYDROGRAPHS FROM SMALL URBAN WATERSHEDS WITH DIFFERENT LAND USE PATTERNS IN BATON ROUGE

A Thesis

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Abstract

Statistics gathered by FEMA indicate that nine of ten federal disasters are related to flooding. Research has demonstrated that increases in flooding can be contributed to urbanization or the construction of new residential and commercial developments (Anderson, 1970; Arnold & Gibbons, 1996; Putnam, 1972). New development has two main problems associated with it. First is the increase in impervious surfaces due to new parking lots, buildings, and streets (Booth & Leavitt, 1999; Seaburn, 1969). Second is the elimination of natural vegetation, which reduces evapotranspiration and lowers the soil's ability to absorb precipitation (Hewlett, 1982). This study first demonstrates the relationship between land use and land cover characteristics associated with urbanization to hydrograph statistics, specifically time to rise and total rise. Secondly to create predictive models of watershed behavior based on these measures. Time to rise is the time between the inception of a storm and the initial rise of stream stage. Total rise is the total rise in stage to its peak, during the entire storm. This study represents a new geospatial approach for studying these relationships.

The study first established a GIS database of land use and land cover characteristics. The second phase performed regression analyses of the hydrograph response variables with the land use and land cover characteristics as independent variables. There were statistically significant relationships between residential development, commercial development and roads with the response variables, time to rise and total rise. As development increases time to rise decreased and total rise increased. The percentage of forest land use, land maintained as contiguous forest, was correlated with total rise. As the percentage of forest land use increased the total rise decreased. This study demonstrates some univariate models that show direct relationships between land use and land cover characteristic and hydrograph response.

1 Introduction

On June 7, 2001, the Baton Rouge area experienced an extreme weather event when Tropical Storm Allison dropped nine and a half inches of rain in twenty-four hours. Before it was over, eighteen to twenty inches of precipitation fell over the six days of the event (NOAA, 2002). President George W. Bush declared the region a federal disaster area on June 11, 2001. According to the US Federal Emergency Management Agency (FEMA, 2001) there were 56,820 applications for federal assistance in the Baton Rouge area. Sixty-nine million dollars were allocated to the region for federal disaster assistance. Statistics gathered by FEMA indicate that nine of ten federal disasters are related to flooding. The last flood event in the Baton Rouge area to be declared a federal disaster occurred in 1993 (LOEP, 2002). The magnitude of the flooding caused by Allison surprised many people because areas that had not flooded previously did this time. This is consistent with research that has demonstrated increases in flooding with urbanization or the construction of new residential and commercial developments (Anderson, 1970; Arnold & Gibbons, 1996; Putnam, 1972). New development has two main problems associated with it. First is the increase in impervious surfaces due to new parking lots, buildings, and streets (Booth & Leavitt, 1999; Seaburn, 1969). Second is the elimination of natural vegetation, which reduces evapotranspiration and lowers the soil's ability to absorb precipitation (Hewlett, 1982).

One approach to dealing with flooding is through land use planning. According to Arnold and Gibbons (1996), proper planning of new development can decrease the probability of flooding, and this should involve a careful analysis of site conditions on a watershed level. This could be combined with strict zoning ordinances to prevent over development of areas (Losco, 1994). The main purpose of this study is first to demonstrate the relationship between land use and land cover characteristics associated with urbanization to hydrograph statistics, specifically time to rise and total rise. Secondly, to create predictive models of watershed behavior based on these measures. Time to rise is the time between the inception of a storm and the initial rise of stream stage. Total rise is the total rise in stage to its peak, during the entire storm. The shape of a hydrograph is a function of watershed characteristics. The timing and amount of storm flow are largely determined by land use and land cover patterns. This is explained by the principal of Horton Overland Flow from Robert E. Horton (1933) and described by Dunne and Leopold (1978). This principal states that there is a maximum limiting rate at which soil can absorb rainfall. If precipitation during the storm exceeds the infiltration capacity the water first accumulates on the soil surface and fills depressions. Once the depressions are filled beyond capacity the water becomes overland flow. The key characteristic of urban areas is impervious surfaces, which allow no water to be absorbed. Therefore, all rain on these impervious areas become overland flow.

In this study, literature from previous studies involving land use characteristics and their effects on natural water flow process will be examined. This will give a background for the understanding of how urban development modifies hydrology. This study examines the concept that urban development changes runoff patterns. It represents a new geospatial approach for studying these relationships. Technology now allows us to obtain large amounts of land use characteristics that can be used in a Geographic Information System (GIS) (Mitchell, 1999). The techniques of obtaining and using this data using GIS will be described in detail. Models described in this study may be able to assist planners, especially in flood prone areas, to determine watershed capacity for future development. This can help minimize flood hazard and other associated impacts.

2 Review of Literature

2.1 Impervious Surfaces

Arnold and Gibbons (1996) indicate that impervious surfaces are comprised of materials that prevent the infiltration of water into the soil. These include rooftops, roads, parking lots, and compacted soils. When development changes the natural landscape, the percentage of land covered by impervious surfaces increases dramatically. Human presence has become synonymous with imperviousness. A given area's population density can be directly correlated with its percentage of impervious surface cover (Stankowski, 1972; Templeton, 1998).

Research by Booth and Leavitt (1999) indicates the contribution of impervious surfaces to the change in runoff processes in an urban landscape is astounding. Almost all of the problems associated with flooding result from the loss of the water-retaining function of the underlying soil. With urbanization, stream channels expand greatly to consume adjacent land that was never before affected by either flooding or erosion. Storm water facilities are overwhelmed by frequent flows far beyond their design capabilities. Because detention times are not long enough, even the best designed and largest storm water pond cannot convert precipitation during the wet season into runoff during the following dry season. According to Bledsoe and Watson (2001) low levels of impervious surfaces (10 to 20 percent) have potential to destabilize streams. Magnitude of this alteration is sensitive to factors of imperviousness including connectivity and conveyance as well as specific characteristics of receiving channels. Alterations are changes in channel morphology, including channel widening and meandering. Clark and Wilcock (2000) state that clearing land for agriculture increased runoff by 50 percent and later development for residential and commercial uses maintained this runoff increase. This lead to channel widening, deepening and increases in floods.

There is a significant rainfall runoff relationship in the urban environment, as shown by G. S. Seaburn (1969). His study took into consideration many complex factors including intensity, duration, areal distribution, direction of storm, antecedent precipitation, soil moisture conditions, climatic conditions affecting evaporation and transpiration, and physical characteristics of draining area. The rainfall-runoff relationship was plotted for storms during the urban and preurban periods. Direct runoff in the urban period ranged from 1.1 to 4.6 times greater than direct runoff during the earlier period, depending on storm size.

Lag time is the basin characteristic most affected by urbanization (Anderson, 1970). Dunne and Leopold (1978) define lag time as the average time interval between the centroid of rainfall excess and the centroid of direct runoff. Research from Anderson (1970) showed lag time for a completely storm-sewered system is about one-eighth that of a comparable natural system. This means complete development of stream channels with 100 percent impervious cover may increase average floods by a factor of eight. This relationship indicates that urban and suburban development significantly increase flood magnitude.

According to Putnam (1972), a significant effect of urbanization is the sharp increase in the rate of peak storm water runoff resulting from the reduced time of concentration. For any given watershed the quicker the water runs off the greater the flood magnitude. Impervious cover and the associated ditching, curbs, drains, and storm sewers all tend to decrease lag time of basins and increase their peak flows.

2.2 Vegetation

Hewlett (1982) states that a majority of precipitation input into a watershed leaves as evaporation, which is more than through stream flow and storage combined. In temperate regions 70 percent of precipitation evaporates from land. This factor is heavily influenced by the evapotranspiration of trees and other plants. Evapotranspiration is the process by which water is absorbed by the root system of plants, moves up through the plant's vascular system, and passes through stomata in the leaves and lenticels in the stem. Thus the water is returned to the atmosphere as vapor. Another factor is interception, the capture of water on surfaces before it hits the ground during precipitation. The total surface area of plant material influences this process. Between storms, evapotranspiration dries out the soil, allowing it to absorb more water.

According to Moll (1989), average tree cover in cities is 30 percent. Most cities have the capacity to accommodate a doubling to 60 percent, which would triple environmental benefits. This is because canopies have heights, widths, and depths. Dimensions of canopies are measurements of volume. Therefore, doubling the amount of tree canopy in a city triples leaf area. When it rains, the leaves and branches slow movement of storm water by 14 percent and thus can help mitigate many of the problems caused by heavy rains.

Cedusky (1992) suggests numerous other benefits of urban forests besides those associated with storm water runoff. Trees help cool cities through shading and the cooling effect of evaporation. They have been shown to cut cooling cost by 10 percent. In winter they can cut heating cost by 4 percent through blocking wind. They also act as natural air filters intercepting airborne particles and absorbing gaseous pollutants.

2.3 Land Use Planning

A new and promising trend being promoted by the U.S. Environmental Protection Agency (USEPA) (1993) is to use watersheds as planning units. A watershed is an area that drains to a common point. This may be a lake, stream, or bay. With knowledge of local topography, watersheds can be clearly defined as geographic units. They form a system or hierarchical organization that can be represented at a number of scales. A regional basin may encompass several local sub basins.

Arnold and Gibbons state that impervious surfaces are important in land use planning. Because of this, they make an excellent starting point for watershed analysis. At regional and community scales land cover can be derived from aerial photographs. Impervious areas are measurable this way. This provides a good compromise between accuracy and cost (Mitchell, 2001; Arnold and Gibbons, 1996). This analysis can be used to guide planning and management within each local watershed. Areas with less impervious zones should emphasize preventive measures that retain existing natural open space. Watersheds with high proportions of impervious surfaces should implement more preventive planning approaches. Focusing on site design that reduces runoff and imperviousness accomplishes this (Arnold and Gibbons, 1996). Gosnold, Lefever, and Todhunter (2000) state that future flood prediction and studies must advance beyond statistical and engineering approaches and factor in the impact of land use, including impervious surfaces and vegetation, on the character of the data used in model calculations.

As described by Losco (1994) another approach to land use planning is zoning. This is a tool used by communities to control and manage development. There are a number of zoning techniques that are environmentally beneficial. Cluster developments are dwellings constructed close together to preserve open space. Down-zoning changes an established zone to require a lower density of developed area. Conditional zoning allows only certain activities under specified conditions. This is usually done to protect water resources in sensitive areas. Open space preservation is the protection of open space and development of buffer zones, especially near water bodies. Some examples are greenways and riparian corridors. The use of public rights of ways for runoff controls such as wet ponds, vegetated swales, or meandering vegetated channels is also suggested.

Douglas (2001) describes another theory in planning that involves defining a carrying capacity. In this approach, built and natural resources have an intrinsic carrying capacity. When this threshold is exceeded, the resource fails to function as intended and negative impacts occur. Land use planning and land use law originate from the idea that cities must look at the entire picture to plan adequately for the future. This begins with creating a comprehensive plan. These plans should include analysis of the carrying capacity of each resource to handle the impact of additional commercial structures, houses, and roads. Once the carrying capacity has been surpassed, financial investments may not provide an adequate remedy. These solutions are to force an area to adhere to a plan of growth based on its limitations.

2.4 Nonpoint Source Pollution and Water Quality

Fisher (1994) states that progress in reducing water pollution have been attributed to the Clean Water Act and the Safe Drinking Water Act. These laws created standards, permits, and enforcement for discharges of industrial and municipal effluent into the nation's waters. Focus has shifted from individual sources to comprehensive watershed wide-planning to address polluted runoff. This runoff is called nonpoint source pollution. According to the USEPA (1994), 40 percent of all waters surveyed in the U.S. were found to not be suitable for swimming and fishing. Nonpoint source pollution is the primary cause of this impairment. Urban runoff ranks second as the most common source of water pollution for lakes and estuaries, and third for rivers. USEPA (1992) describes the major categories of nonpoint source pollutants, which include pathogens, nutrients, toxic contaminants, debris, and sediment. Pathogens are disease-causing microorganisms, that pose health hazards. Nutrients, such as nitrogen and phosphorous, can lead to algal blooms. These events deplete dissolved oxygen in the water and cause fish kills. Toxic contaminants, like heavy metals and pesticides, pose threats to the health of aquatic organisms and their consumers, including humans. Debris can be hazardous to animals and humans. These conditions also degrade the aesthetic quality of scenic waterways. Sediment has an effect on aquatic ecology by smothering vegetation. Also, many other pollutants tend to adhere to eroded soil particles (USEPA, 1992).

Impervious surfaces do not generate pollution; they: (1) contribute to changes in hydrology that degrade waterways; (2) are major components of the land uses that generate pollution; (3) prevent natural pollutant processing from plants and microorganisms in the soil; (4) serve as a transport system that channels pollutants directly into waterways (Arnold and Gibbon, 1996). In a study in East Baton Rouge Parish by Demcheck, Frederick, and Johnson (1998), residential sites were shown to produce more total suspended solids, lead, phosphorous, and nitrogen than the commercial, industrial, and undeveloped sites. The study also showed that lead exceeded the USEPA criteria at all but the undeveloped sites.

3 Materials and Methods

3.1 Description of the Study Area

Seven watersheds were chosen for this study located primarily in East Baton Rouge Parish, Louisiana (see Figure 1). The watersheds are located in the Amite River Basin. The watersheds were delineated as the area that drains through the seven chosen U.S. Geographic Survey (USGS) stations. Station information is displayed in Table 1.

Table 1: Station Information for Sample Watersheds.

USGS Station Number	Watershed Name	Area (sq mi)
07378100	Beaver Bayou	10.272
07378722	Claycut Bayou	8.025
07379960	Dawson Creek	15.621
07378650	Jones Creek	8.550
07379100	N. Branch Ward Creek	6.391
07379050	Ward Creek	8.419
07377780	White's Bayou	44.438

These watersheds were chosen to represent different levels of urbanization. Two of the watersheds are located north of Baton Rouge and are primarily rural areas with a high percentage of agricultural and forest land. These watersheds have little urban development and can be considered as a relatively natural control for the study. The lower five watersheds are located in the city of Baton Rouge. They are all urban watersheds with varying degrees of urbanization. These watersheds differ primarily in the proportion of residential and commercial land uses. Because of the large proportion of tree canopy, the residential areas can be described as being an

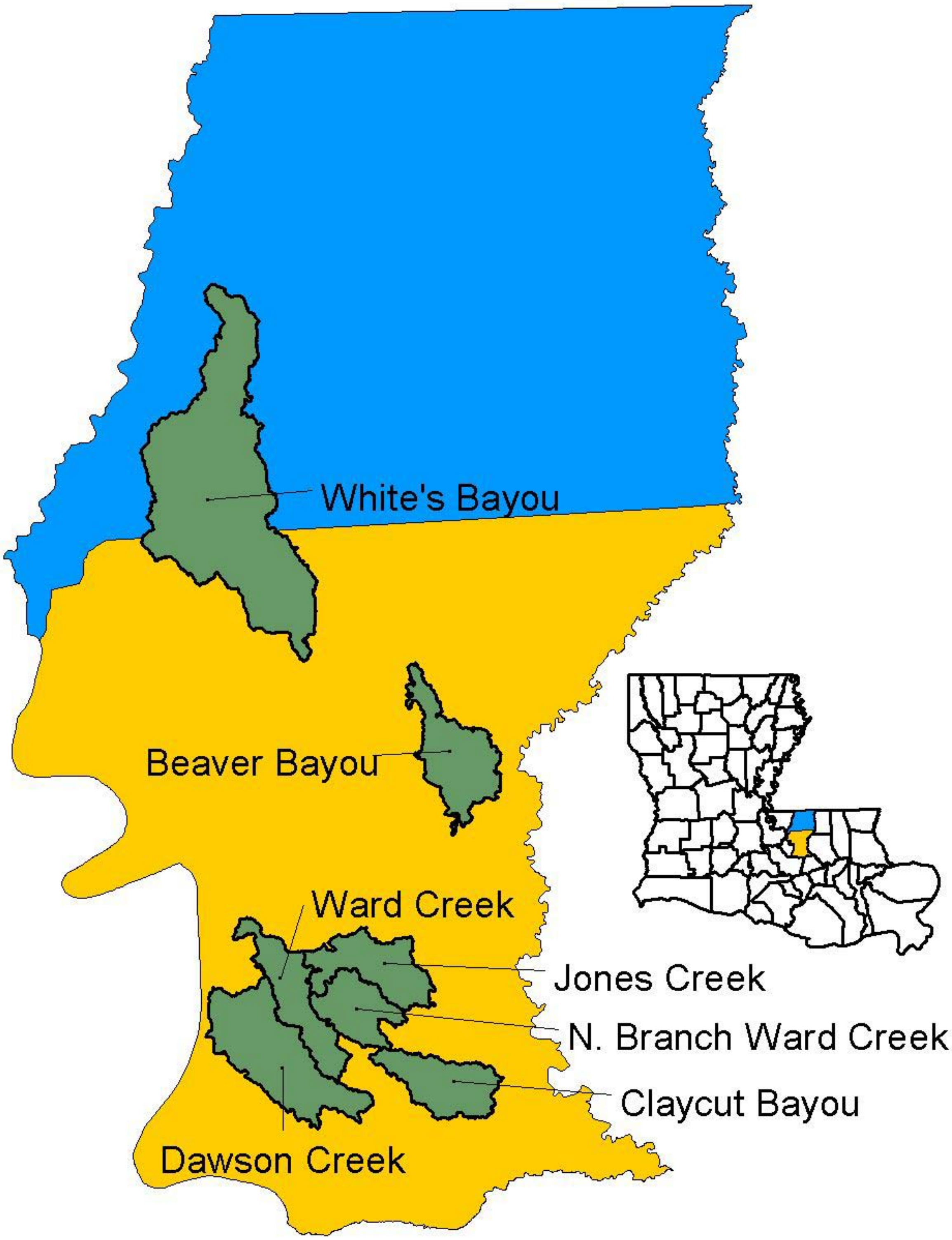

Figure 1. Study Area

urban forest (Mitchell, 1999). The areas described as commercial are dominated by impervious surfaces. These study watersheds are classic examples of the influence of urbanization. The watershed morphology has been greatly altered by drainage projects that have changed stream channels and drainage patterns.

3.2 Software

All digital geospatial data manipulation was performed using *ArcInfo*® 8.0 (ESRI, 1999a) and *Arcview*® 3.2 (ESRI, 1999b). *Spatial Analyst* 2.0 was used as an extension of *Arcview* (ESRI, 2000). An *Arcview*-based preprocessor for hydrologic, hydraulic, and environmental modeling called *CRWR-PrePro* (version prepro03a) was used (Crwr-PrePro, 2002). All other data manipulation for this project was done with the *SAS System*® version 8 (SAS Institute Inc., 1999).

3.3 Spatial Data Sources

For this project data was obtained from many sources. Both the 1:24,000 DLG hydrography and 30m Digital Elevation Models (DEM) were available from the USGS Geographic Data Download website (USGS, 2002a). Both the hydrography (USGS, 1986) and DEM (USGS, 1990) are made available in the Spatial Data Transfer Standard (SDTS) format. Each 7.5 minute quadrangle resided in one file. Transpiration features were obtained from the US Census Bureau in a GIS readable format called Topologically Integrated Geographic Encoding and Referencing system (TIGER) line files (US Census Bureau, 2002). Files were obtained from the Redistricting Census 2000 Tiger/Line web page (Geography Network, 2002). Residential and commercial sites were obtained from *Selectphone* cd (Global Business International, 1997). GAP vegetation data can be attained from the National GAP Searchable

Database (USGS, 2002b). Canopy and land use data set obtained from previous work (Mitchell, 1999). All data were imported into *ArcInfo* coverages.

3.4 Projection

The *ArcInfo* coverages used for this project were all placed in the same projection. All analyses were performed using UTM Zone 15 meters, NAD 1927, and Clarke 1866 as the spheroid.

3.5 Watershed Delineation

The 30m Digital Elevation Models (DEM) and 1:24,000 DLG hydrography are required to perform watershed delineation for the study areas. Four 1:24,000 quads were needed. The hydrography data required further processing. All streams that did not connect to another channel were taken out. This was done to ensure complete flow could be established throughout the stream network. The different quad level hydrography coverages were then merged into a single seamless database, as were the DEM coverages.

The delineation was performed using *Arcview* and *CRWR-PrePro*. The *CRWR-PrePro* is added to *Arcview* as an extension. The software uses the DEM and hydrography in a step-by-step procedure:

(1) <u>Burn-in Streams</u> – The process of lowering the elevation of the grid cells where the the hydrography is located to ensure the water will flow into them.

(2) <u>Fill in DEM Sinks</u> – All sinks, low-lying areas such as ponds and wetlands, are elevated to keep them from accumulating flow.

(3) <u>Compute the Flow Direction Grid</u> – Creates a grid that defines the direction of downhill flow from cell to cell.

(4) Compute the Flow Accumulation Grid – Calculates where water travels from each cell and how many cells drain (accumulate) into any particular cell.

(5) Construct the Basic Stream Network – Create a stream network by choosing cells with a specified accumulation value.

(6) Segment Streams into Stream Links – Assigns each stream segment a unique ID.

(7) Find Link Outlets – Identifies the cell with the highest accumulation value per stream link.

(8) Add outlets – The stream gauge are located on the grid, so they can be used as the point at which the delineation begins.

(9) Delineate the Watersheds – Watersheds are delineated for each stream link.

(10) Vectorize the Stream and Watershed Grids – The grid data are converted into vector data format.

(11) Merge Sub watersheds – All sub watersheds that flow through a given stream gauge is merged.

Once each watershed is created it is converted into an *Arcview* shapefile. These shapefiles can be imported into coverages and "built" for polygon topology. This process ensures all polygons are closed and have a label point. The final step is to add attributes to the database.

3.6 Roads

Roads are important to this study because they are a large component of the impervious surface in a watershed (Arnold et al., 1996; Putnam, 1972). In addition, they provide a direct path for water to flow from upland areas (Mitchell, 1999). The roads' coverage is intersected with watershed coverages to isolate those roads in each watershed. This data layer can be seen in the Appendix as Figure A-1 and A-2. This data layer is used to calculate the total number of road miles. These figures are an under estimate of the actual road mileage. The actual mileage is larger due to local topography. From the road miles, the density of roads were calculated for each watershed.

3.7 Commercial and Residential Sites

The total number of residential and commercial sites located within each watershed can be used as a measure of development. These are an indicator of impervious surfaces (Arnold & Gibbons, 1996; Anderson, 1970). The *Selectphone* cd contains an address and geographic location for all phone numbers in a selected area. These phone numbers are subdivided into residential and commercial numbers. These data only represent locations with phones. For residential locations this results in a small underestimate. However, commercial locations are probably more accurate, because they are less likely to not have a phone. The watershed polygons are intersected with these points to create two coverages; one represents the number of commercial sites and the other residential sites in each watershed. These data layers can be seen in the Appendix as Figure A-3 through A-6. From these coverages the density of residential and commercial sites were calculated for each watershed.

3.8 GAP

The Gap Analysis Program (GAP) maps the distribution and extent of existing vegetation. The vegetation is categorized into a classification scheme. The classes found in the watersheds are given in Table 2. For this study the classifications of vegetated urban and non-vegetated urban are very important. Vegetation plays a crucial role in the hydrologic cycle. Plants intercept precipitation, return water to the atmosphere through evapotranspiration and dry out the soil column to allow greater absorption of water (Hewlett, 1982). For these reasons, the vegetation data will be studied as indicators of a watershed's storm water runoff behavior. These data were intersected with the watershed polygons to produce a coverage depicting the vegetation characteristics of each watershed. The total area of each classification category was calculated for each watershed. These data layers can be seen in the Appendix as Figures A-7 and A-8.

Table 2: Land Cover Classes for GAP Data

Fresh Marsh	Wetland Forest-Deciduous
Wetland Forest-Mixed	Upland Forest-Deciduous
Upland Forest-Evergreen	Upland Forest-Mixed
Dense Pine Thicket	Wetland Scrub/Shrub-Deciduous
Upland Scrub/Shrub-Deciduous	Upland Scrub/Shrub-Mixed
Upland Scrub/Shrub-Evergreen	Agriculture-Cropland-Grassland
Vegetated Urban	Non-Vegetated Urban
Wetland Barren	Upland Barren

3.9 Land Use and Canopy Classes

These data were created using aerial photographs at the scale of 1:18,000. They were taken in November of 1993 (East Baton Rouge Parish Tree Commission, 1995). Polygons were digitized over the aerial photographs creating a coverage of different land use and canopy classes, which can be seen in Table 3. The use of these data sets is based on the aforementioned importance of indicators of impervious surfaces and vegetation. The original coverage was modified to separate commercial and residential development. This was done by placing the residential and commercial point coverages over the land use map and digitizing polygons around areas dominated by either commercial or residential points. In this manner the two were separated into classes. These data were intersected with the watershed polygons to create two new coverages representing each land use class for each watershed. The total area of land use and canopy class was calculated. This was used to calculate the percentage of land use and canopy class in each watershed. These data layers can be seen in the Appendix as Figures A-9 through A-12.

Table 3: Canopy and Land Use Classes

Canopy Classes	Land Use Classes
Forest = > 50% canopy closure	Agriculture
Transition = 10% - 50% canopy closure	Commercial
Open = < 10% canopy closure	Forest
	Open
	Residential
	Water

3.10 Hydrograph and Precipitation Data

When stream stage or discharge is plotted against time, the resulting curve is called a hydrograph. Total flow, seasonal distribution of flow, daily flow, peak flow, and frequency of various critical flow rates can all be computed from the hydrograph (Hewlett, 1982). A sample hydrograph can be referenced in Figure 2. Hydrograph and precipitation data were obtained from the USGS Water Resources Division District. Water surface elevation in (ft.) and cumulative precipitation in (in.) were available for all seven watersheds. These data were retrieved for the period of Oct. 1998 through Sept. 2000. This time period was generally

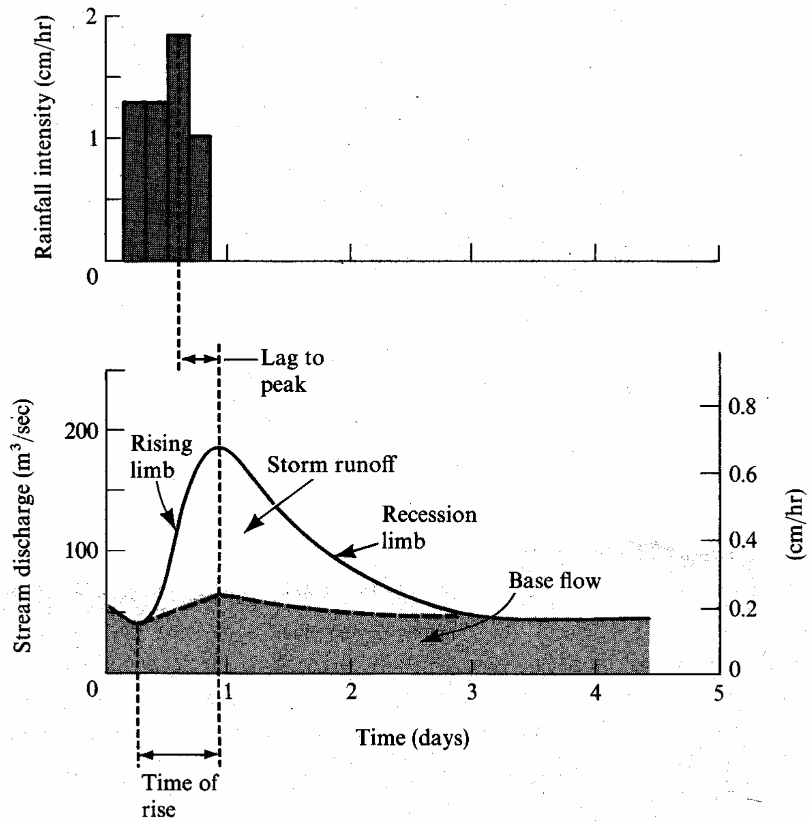

Figure 2. Sample hydrograph (Modified from Dunne & Leopold, 1978).

considered as a drought in south Louisiana. This is important to note because the streams are at or below base flow conditions, which allows storm flow to be better identified.

Stage samples are taken at each gauge once per hour. Only data sampled during rain events were needed for this study and were extracted from the data set. This data set of storms was further scrutinized to eliminate storms that did not appear in at least three watersheds. To ensure uniform input for each storm, storms were also eliminated if the precipitation standard deviation exceeded 0.25 between watersheds. The final data set includes sixteen storms.

The storm intensity (in/hr) was calculated for each storm. This was done by dividing the total precipitation of the storm by the time to the stage peak. The average storm volume was also calculated for each storm. This calculation is done by multiplying the total precipitation (in) by the individual watershed area (mi^2). This was then converted to acre feet.

4 Results

4.1 Time to Rise as a Function of Land Use Characteristics

To evaluate the relationship between time to rise and land use characteristics, simple linear regressions were performed using time to rise as the dependent variable. Time to rise is the time from the beginning of a storm until the first response in the stream stage at the gauge. In this study time to rise is measured in hours. The independent variables in this study are the land use characteristics described in the Materials and Methods section. The regressions were performed on each of the storms individually and for the data set as a whole.

The density of residential sites and the percentage of residential land use both showed a strong relationship with time to rise. These are two different measures of urbanization. Regression of the entire data set for residential density yielded an $r = -0.54713$ ($p = < 0.0001$) and for percentage of residential land use it was $r = -0.68057$ ($p = < 0.0001$). The graphs of all individual storms showed the slopes to be negative. This demonstrates that increased housing leads to a decrease in time to rise. Figure 2 displays time to rise and density of residential sites relationship. Figure 3 shows how time to rise and percentage of residential land use are related. Summary statistics for these regressions are shown in Table 4 (residential density) and Table 5 (percentage of residential land use).

The density of commercial sites showed a statistically significant relationship with time to rise as well. The regression of the complete data set resulted in an $r = -0.53131$ ($p = < 0.0001$). Commercial sites can vary a great deal in size, unlike residential sites where houses are generally the same size. For example a gas station and an oil refinery are both counted as a single site but are vastly different in size. Commercial locations, however, do

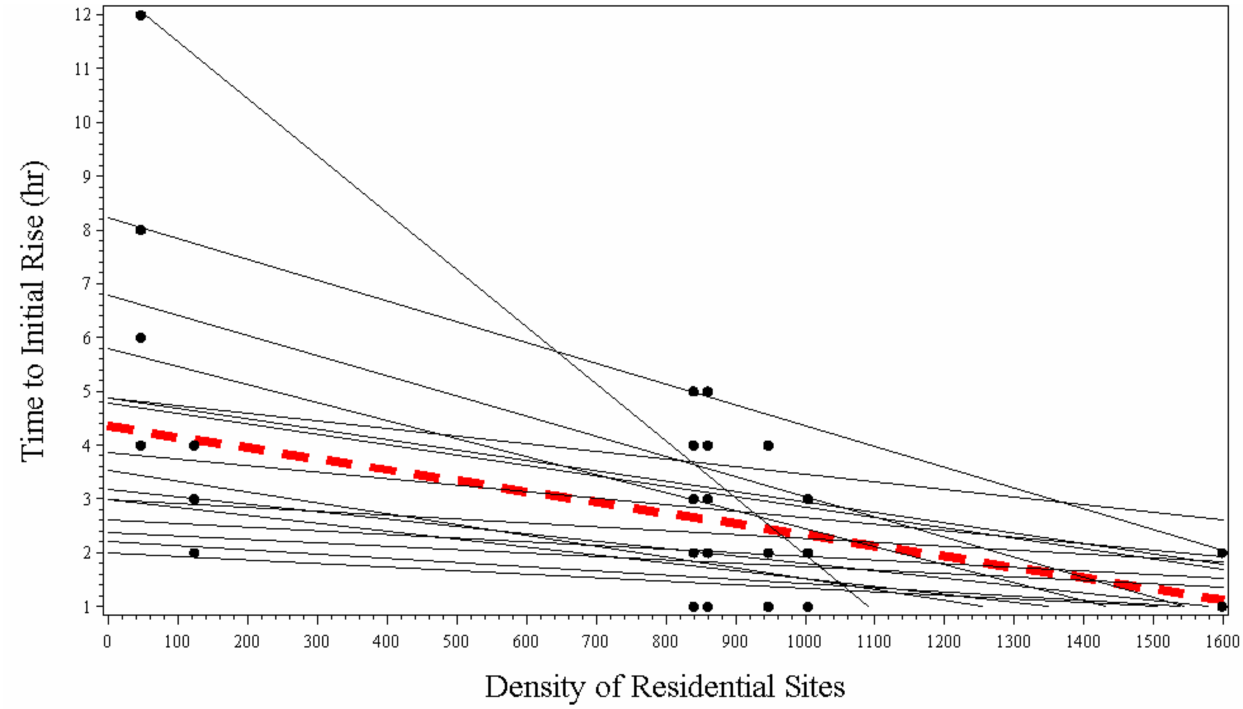

Figure 3. Time to Initial Rise as a Function of Residential Density. Dashed red represents a regression of entire data set, solid lines represent individual storms.

Table 4: Statistics from Regressions of Time to Initial Rise as a Function of Residential Density

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	0.974561	-0.00193	0.6834	0.5251	0.974561	0.1733
11/14/1998	0.480219	-0.00148	0.7233	0.6541	0.480219	0.0319
12/10/1998	1.25343	-0.00121	0.3385	0.0077	1.25343	0.4182
12/12/1998	0.326958	-0.00071	0.8396	0.6793	0.326958	0.2623
12/23/1998	1.75366	-0.00141	0.1707	-0.0366	1.75366	0.4155
12/28/1998	0.506229	-0.00335	0.9309	0.9136	0.506229	0.0018
1/02/1999	0.455083	-0.00078	0.4477	0.3097	0.455083	0.1461
1/22/1999	0.487414	-0.00066	0.4061	0.2081	0.487414	0.2475
2/17/1999	1.21600	-0.00193	0.4455	-0.1090	1.21600	0.5348
3/02/1999	0.347760	-0.00063	0.5465	0.3953	0.347760	0.1534
7/07/1999	0.019851	-0.00138	0.9994	0.9988	0.019851	0.0155
9/06/1999	0.839940	-0.00375	0.7910	0.6864	0.839940	0.1106
12/18/1999	0.118897	-0.00387	0.9992	0.9984	0.118897	0.0178
12/20/1999	0.867797	-0.00067	0.2469	-0.1296	0.867797	0.5031
1/03/2000	1.05186	-0.01061	0.9407	0.8815	1.05186	0.1566
7/23/2000	0.783745	-0.00202	0.7290	0.6387	0.783745	0.0656
Avg. Slope of Storms	-	-.00059	-	-	-	-
All Data	4.17343	-0.00182	0.2965	0.2862	1.35424	< 0.0001

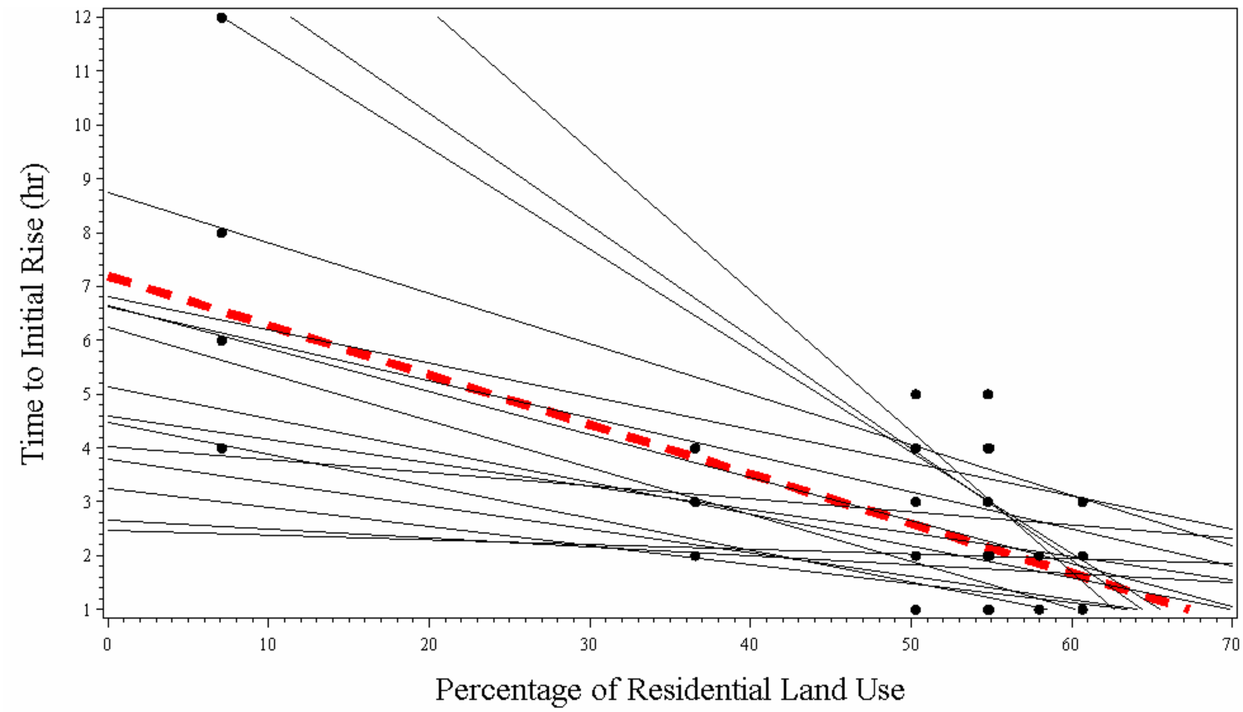

Figure 4. Time to Initial Rise as a Function of Residential Land Use. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 5: Statistics from Regressions of Time to Initial Rise as a Function of Percentage of Residential Land Use.

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	6.61446	-0.06881	0.2812	-0.0782	1.46845	0.4697
11/14/1998	6.23974	-0.08705	0.8330	0.7913	0.373033	0.0111
12/10/1998	4.01256	-0.02404	0.0433	-0.4350	1.50734	0.7918
12/12/1998	4.58302	-0.04348	0.9896	0.9791	0.083444	0.0652
12/23/1998	6.80619	-0.06156	0.2626	0.0168	1.13057	0.3773
12/28/1998	6.64476	-0.08004	0.8775	0.8469	0.673966	0.0059
1/02/1999	3.78462	-0.04349	0.4620	0.3275	0.449160	0.1374
1/22/1999	3.23872	-0.03531	0.3742	0.1657	0.500304	0.2729
2/17/1999	14.3568	-0.20757	0.9372	0.8743	0.409353	0.1613
3/02/1999	2.65286	-0.01638	0.1208	-0.1723	0.484211	0.5666
7/07/1999	5.12387	-0.05910	0.9441	0.8881	0.193104	0.1520
9/06/1999	17.3635	-0.26125	0.6043	0.4064	1.15570	0.2227
12/18/1999	8.75345	-0.09395	0.7968	0.5936	1.91241	0.2977
12/20/1999	2.47054	-0.00896	0.0143	0.4786	0.992827	0.8804
1/03/2000	13.3386	-0.18857	0.9648	0.9296	1.40355	0.1201
7/23/2000	4.47164	-0.05936	0.9468	0.9290	0.347358	0.0053
Avg. Slope of Storms	-	-0.02018	-	-	-	-
All Data	7.19245	-0.09207	0.4632	0.4552	1.31880	< 0.0001

not vary as much as residential areas do with respect to landscape. Most commercial areas are almost a hundred percent impervious. All slopes for single storm events were negative, indicating an increase in commercial development results in a decrease in time to rise. The regression plots are depicted in Figure 4 and summary statistics in Table 6.

The percentage of commercial land use and the percentage of residential land use were combined to form the percentage of total urban land use. This also showed a highly significant relationship to time to rise. The regression for the total data set gave an $r = -0.57513$ ($p = < 0.0001$). Figure 5 and Table 7 summarize this relationship. All storm slopes were negative indicating a rise in urban development results in a lower time to rise.

Road density proved to be a good indicator of urban development. This variable only takes into consideration road length and not width. This can be a problem as some of the watersheds have Interstate 10 running through them and it receives the same weight as a local road. When the entire data set was regressed against time to rise it gave very similar results to the other urban land use characteristics. It produced an $r = -0.57550$ ($p = < 0.0001$). The relationship can be seen in Figure 6 and summary statistics in Table 8. All slopes were negative and mostly consistent from one storm to the next. This indicates as the amount of roads increase time to rise decreases. Roads are a good example of impervious surfaces and many are designed to shed water directly into streams. It is also important to note that urban development often extends along roads.

In all of the time to rise regressions, the slopes for each storm were consistently negative as urbanization increases. The only differences were the changes in regression constant. Examining the summary statistics for each storm shows this. The average slope is given for the individual storms and is very close to the slope of the entire data set. This may be explained by

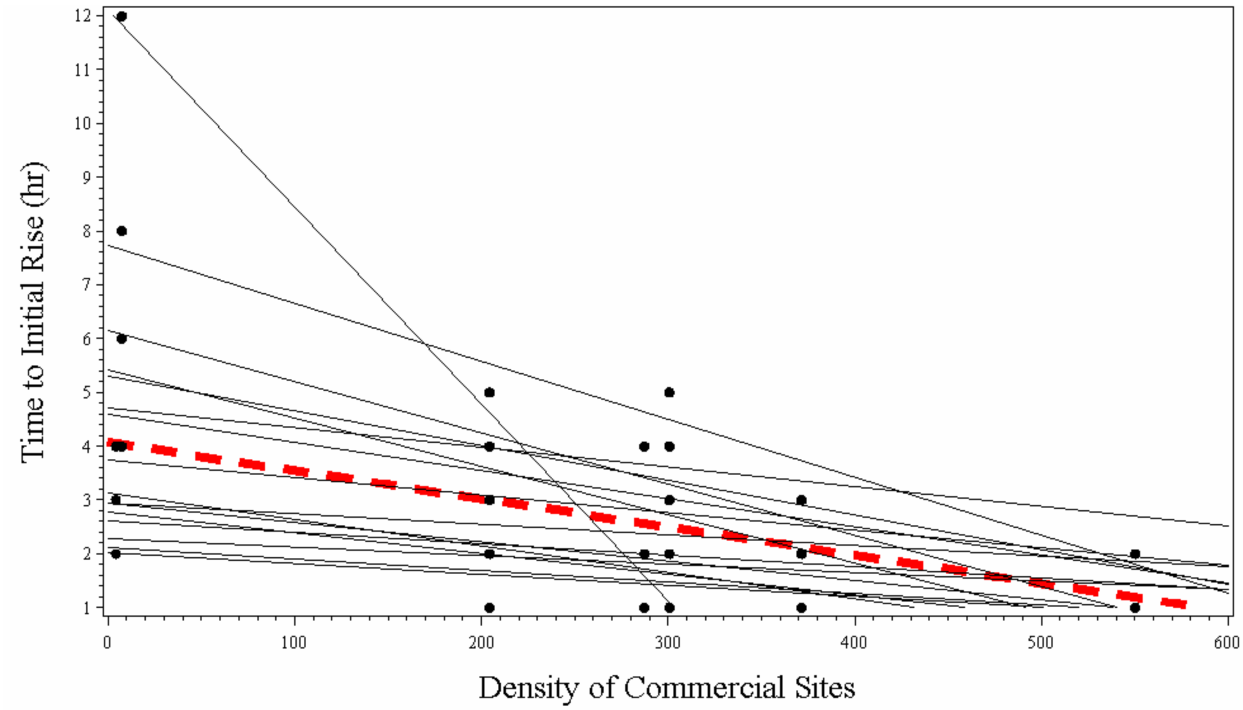

Figure 5. Time to Initial Rise as a Function of Commercial Density. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 6: Statistics from Regressions of Time to Initial Rise as a Function of Commercial Density

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	4.58046	-0.00521	0.7022	0.5533	0.945159	0.1620
11/14/1998	2.77485	-0.00387	0.7334	0.6667	0.471385	0.0295
12/10/1998	3.74618	-0.00328	0.3524	0.0286	1.24018	0.4064
12/12/1998	2.93985	-0.00196	0.8969	0.7937	0.262214	0.2081
12/23/1998	4.70331	-0.00364	0.3963	0.1950	1.02297	0.2551
12/28/1998	5.40870	-0.00897	0.8771	0.8464	0.674966	0.0059
1/02/1999	2.11349	-0.00214	0.4994	0.3743	0.433253	0.1164
1/22/1999	2.01240	-0.00202	0.5290	0.3721	0.434031	0.1637
2/17/1999	5.29747	-0.00645	0.5170	0.0340	1.13489	0.4862
3/02/1999	2.28262	-0.00159	0.4928	0.3238	0.367751	0.1863
7/07/1999	2.94825	-0.00362	0.8986	0.7972	0.260019	0.2063
9/06/1999	6.15076	-0.00953	0.8617	0.7926	0.683197	0.0717
12/18/1999	7.74016	-0.01078	0.9755	0.9510	0.663836	0.1000
12/20/1999	2.59943	-0.00212	0.3667	0.0501	0.795797	0.3944
1/03/2000	12.0956	-0.03661	0.9895	0.9791	0.765765	0.0653
7/23/2000	3.13628	-0.00495	0.5508	0.4010	1.00908	0.1510
Avg. Slope of Storms	-	-0.00224	-	-	-	-
All Data	4.06683	-0.00524	0.2823	0.2716	1.52490	< 0.0001

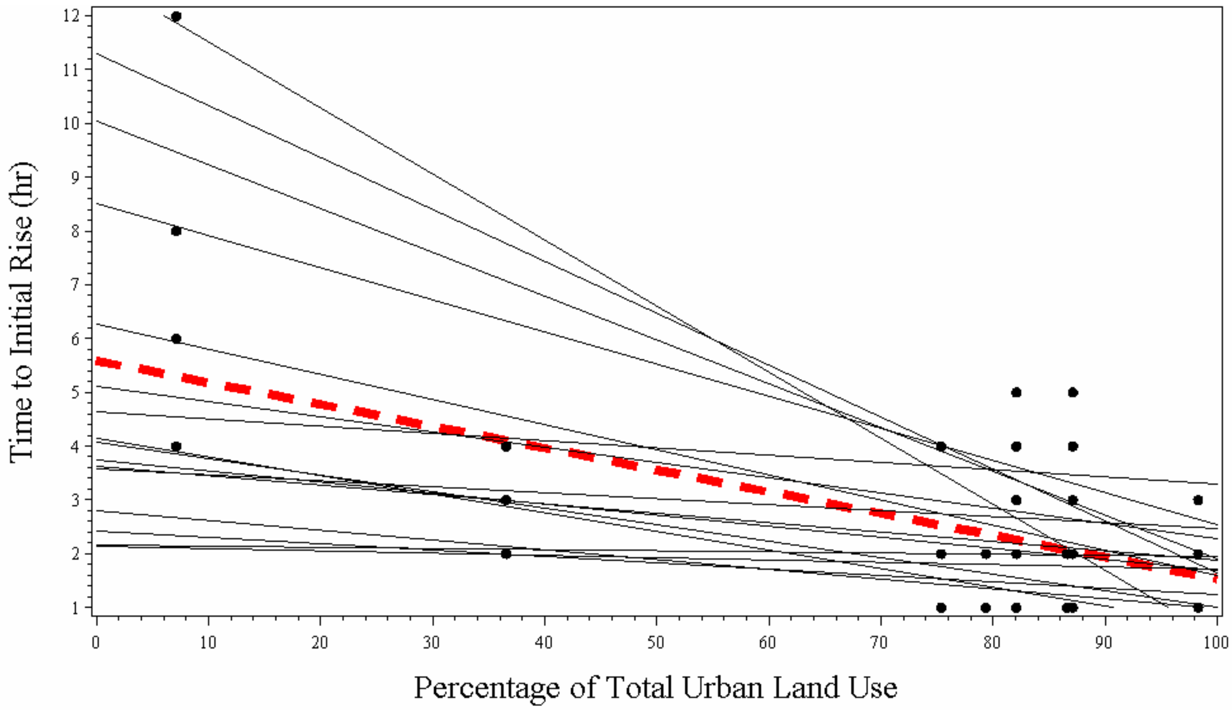

Figure 6. Time to Initial Rise as a Function of Percentage of Total Urban Land Use. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 7: Statistics from Regressions of Time to Initial Rise as a Function of Percentage of Total Urban Land Use

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	5.11190	-0.02845	0.2907	-0.0640	1.45877	0.4609
11/14/1998	4.08121	-0.03081	0.6568	0.5710	0.53476	0.0505
12/10/1998	3.56436	-0.01097	0.0546	-0.4181	1.49845	0.7664
12/12/1998	3.61197	-0.01731	0.9682	0.9363	0.14571	0.1142
12/23/1998	4.63513	-0.01348	0.0799	-0.2268	1.26287	0.6449
12/28/1998	6.26096	-0.04666	0.8057	0.7572	0.84876	0.0152
1/02/1999	2.41651	-0.01180	0.2144	0.0180	0.54277	0.3551
1/22/1999	2.79893	-0.01821	0.6324	0.5098	0.38347	0.1078
2/17/1999	10.04512	-0.08135	0.2174	-0.5652	1.44462	0.6912
3/02/1999	2.12955	-0.00429	0.0526	-0.2631	0.50262	0.7105
7/07/1999	3.74934	-0.02064	0.9919	0.9838	0.07356	0.0574
9/06/1999	11.29344	-0.09647	0.1970	-0.2045	1.64626	0.5562
12/18/1999	8.50611	-0.05980	0.7924	0.5848	1.93307	0.3012
12/20/1999	2.15533	-0.00205	0.0046	-0.4931	0.99769	0.9321
1/03/2000	12.74460	-0.12289	0.9282	0.8563	2.00563	0.1727
7/23/2000	4.14969	-0.03472	0.8281	0.7708	0.62424	0.0320
Avg. Slope of Storms	-	-0.03166	-	-	-	-
All Data	5.58558	-0.04059	0.3308	0.3208	1.47248	< 0.0001

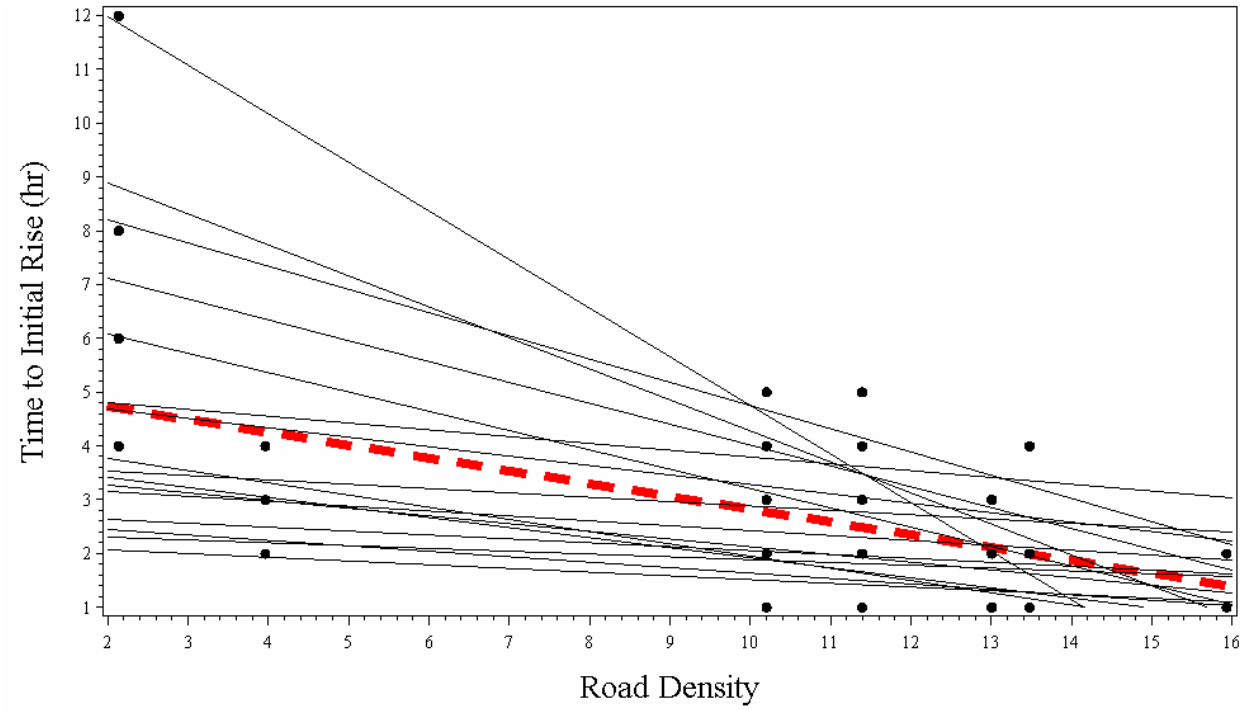

Figure 7. Time to Initial Rise as a Function of Road density. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 8: Statistics from Regressions of Time to Initial Rise as a Function of Road Density

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	5.02522	-0.17463	0.4197	0.1296	1.31941	0.3521
11/14/1998	3.79389	-0.18773	0.8895	0.8619	0.303431	0.0048
12/10/1998	3.70348	-0.08222	0.1175	-0.3237	1.44772	0.6572
12/12/1998	3.32019	-0.08996	0.9451	0.8903	0.191228	0.1505
12/23/1998	5.05041	-0.12551	0.2502	0.0003	1.13999	0.3907
12/28/1998	6.79704	-0.35946	0.9913	0.9892	0.179194	< 0.0001
1/02/1999	2.63519	-0.10018	0.5629	0.4537	0.404845	0.0857
1/22/1999	2.19295	-0.06861	0.3241	0.0988	0.519962	0.3156
2/17/1999	7.87964	-0.38769	0.5964	0.1928	1.03741	0.4382
3/02/1999	2.41221	-0.05297	0.2898	0.0530	0.435191	0.3493
7/07/1999	3.55255	-0.14307	0.9778	0.9555	0.121768	0.0953
9/06/1999	10.0331	-0.57640	0.9086	0.8630	0.555296	0.0468
12/18/1999	9.06140	-0.43088	0.9905	0.9810	0.413001	0.0621
12/20/1999	2.78859	-0.07316	0.2095	-0.1857	0.889074	0.5422
1/03/2000	13.7703	-0.90269	0.9911	0.9823	0.704269	0.0600
7/23/2000	4.20763	-0.22649	0.8229	0.7639	0.633568	0.0335
Avg. Slope of Storms	-	-0.08639	-	-	-	-
All Data	5.20356	-0.23835	0.3312	0.3212	1.47202	< 0.0001

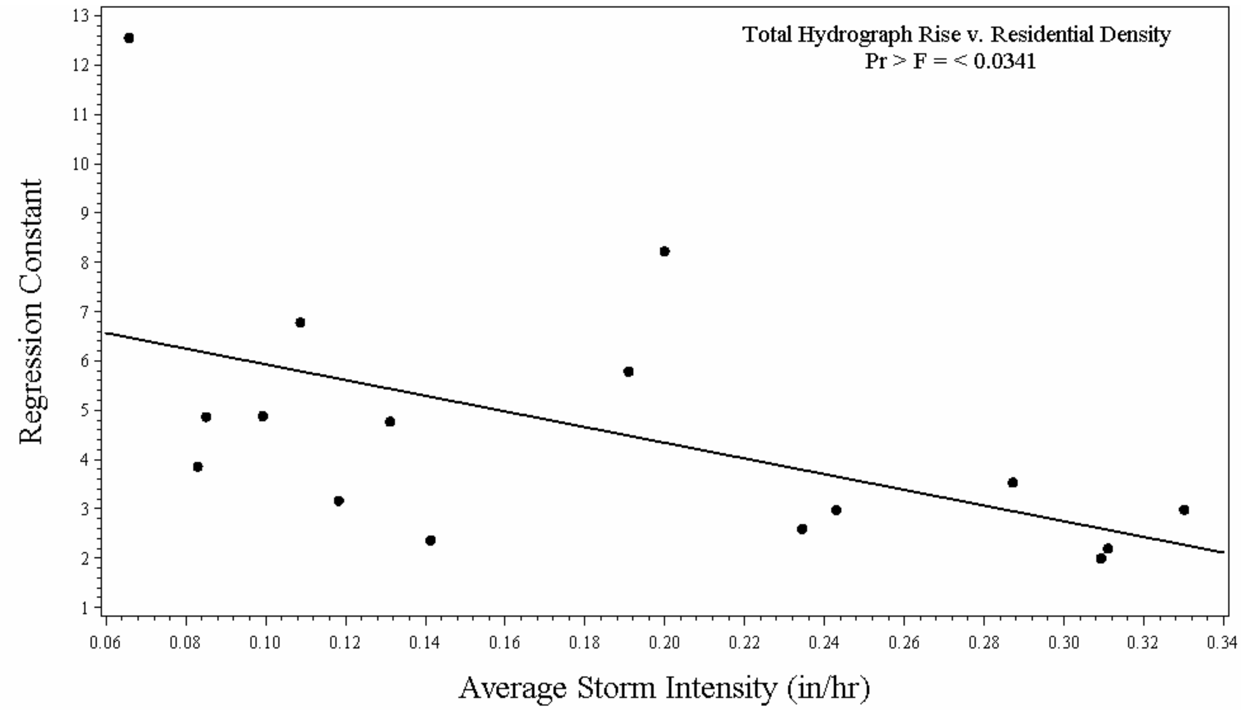

Figure 8. Regression Constant as a Function of Average Storm Intensity.

differences in storm intensity. The regression constants for each of the time to rise against land use characteristic relationships were plotted against the average storm intensity of the storms in each watershed. These plots can be seen in Figures 8 through 12.

4.2 Total Rise as a Function of Land Use Characteristic

To examine the relationship between total rise and land use characteristics simple linear regressions were performed using total rise as the dependent variable. Total rise is the total rise of stage height from the base flow stage to the hydrograph peak. The independent variables used for this study were the land use characteristics described in the Materials and Methods section. The regressions were performed on each of the storms individually, and as a complete data set. The regressions for the density of residential sites and the percentage of residential land use both resulted in significant relationships. The regression for residential density for the whole data set yielded an $r = 0.48488$ ($p = < 0.0001$). The regression for percentage of residential land

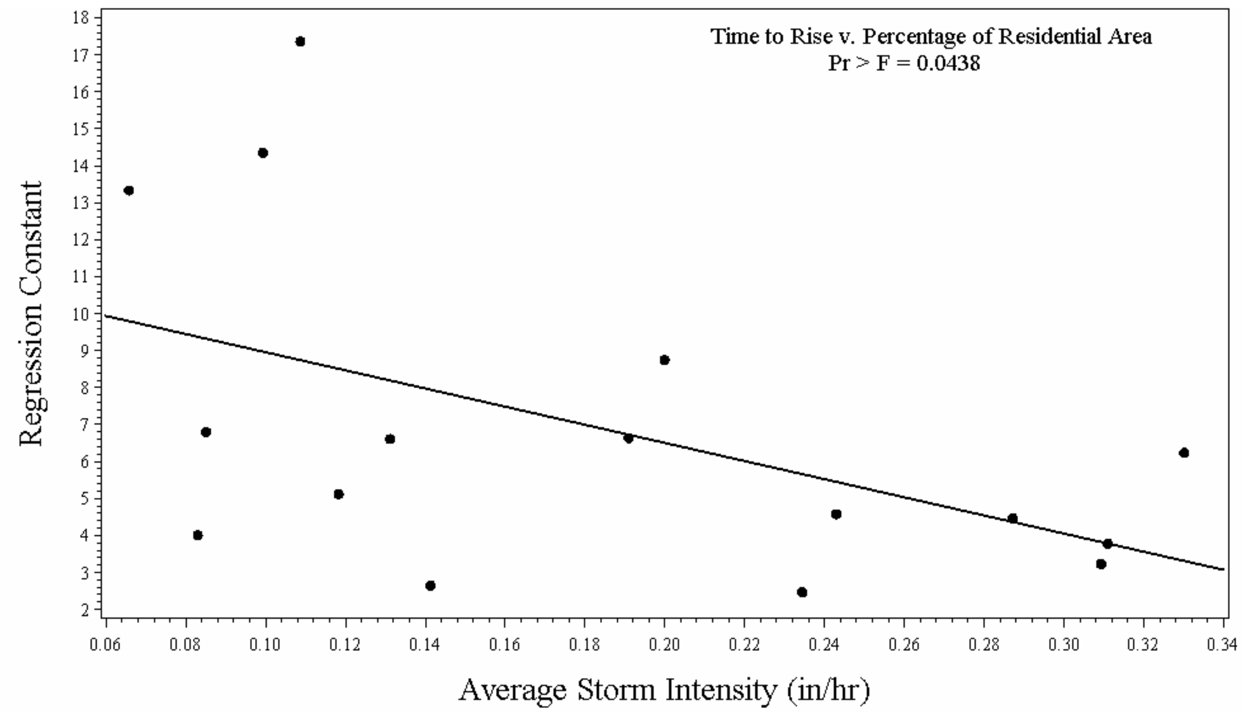

Figure 9. Regression Constant as a Function of Average Storm Intensity.

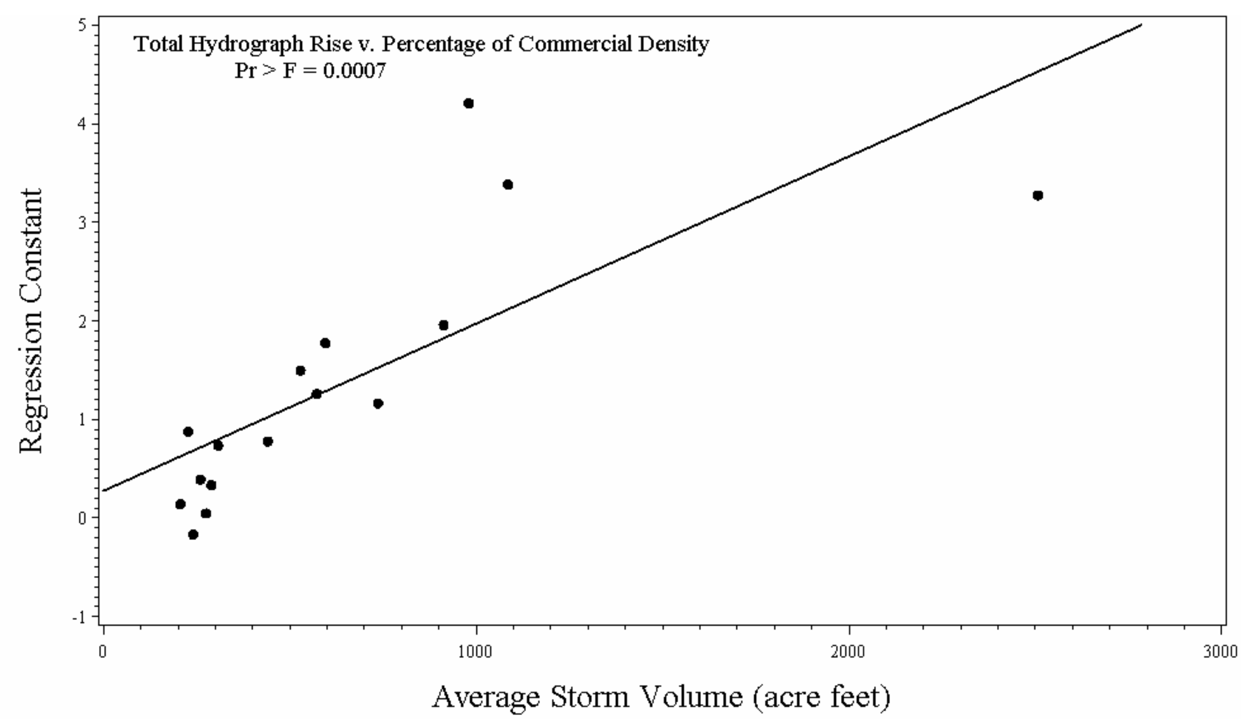

Figure 10. Regression Constant as a Function of Average Storm Volume.

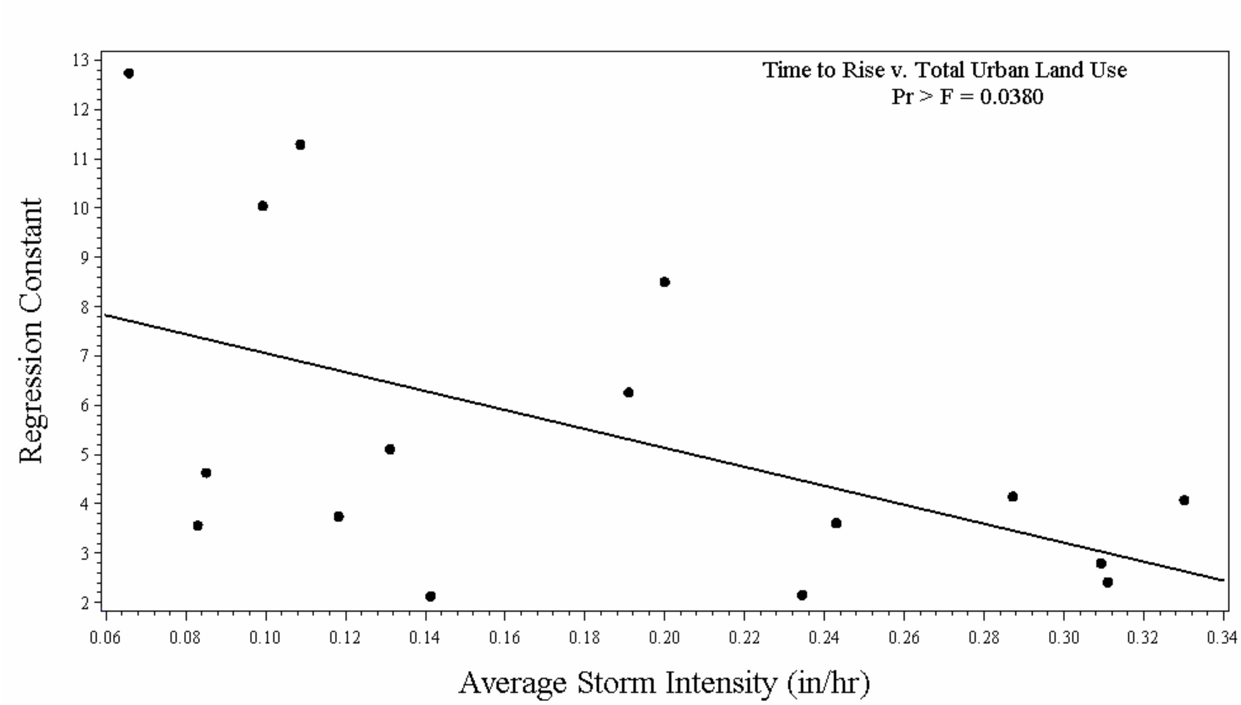

Figure 11. Regression Constant as a Function of Average Storm Intensity.

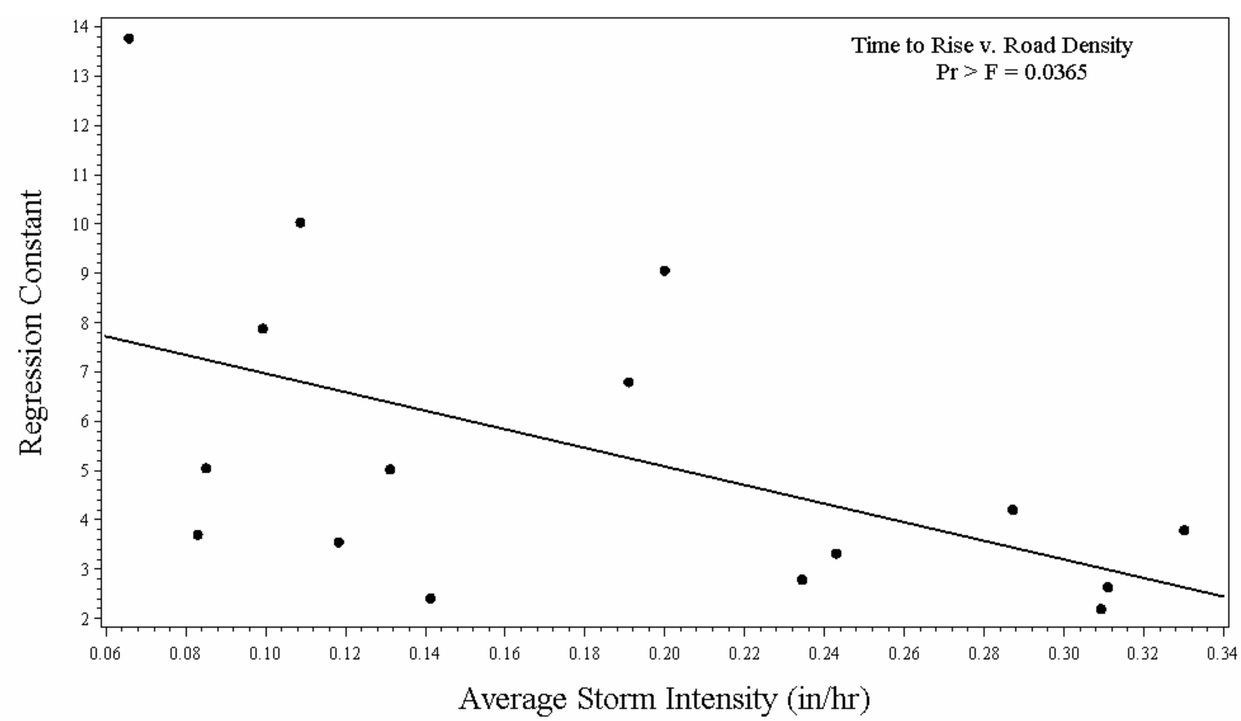

Figure 12. Regresion constant as a Function of Average Storm Intensity.

use showed an r = .28136 (p = 0.0196). These relationships are shown Figure 13 and Table 9 (residential density). Figure 14 and table 10 depict the relationship of total rise with percentage of residential land use. Both features had consistently positive slopes for the regressions performed on individual storms. This demonstrates that an increase in residential development increases the total stage rise of a stream in a given watershed.

The density of commercial sites has a strong association to total rise. The regression against the whole data set resulted in an r = 0.46564 (p = < 0.0001.) The relationship can be seen in Figure 15 and summarized in Table 11. The slopes were consistently positive demonstrating that an increase in commercial development results in an escalation in the total rise of stage height. This result is not surprising, because commercial land use is generally comprised of completely impervious surfaces.

The percentage of GAP urban was established by combing the percentage of GAP nonvegetated urban and GAP vegetated urban. This variable has a significant relationship to total rise. The regression yielded an r = 0.35905 (p = 0.0024) for the entire data set. This relationship is shown in Figure 16 and summary statistics in Table 12. Total urban land use also showed a relation to total rise with an r = 0.31961(p = 0.0074) for the regression against the complete data set. This regression plot is available in Figure 17 with the summary statistics in Table 13. Both of these measures of total urban development had consistently positive slopes implying that an increase of urban development including both residential and commercial results in an increase in total rise in stage height.

A strong a relationship is present between road density and total stage rise. The regression for the entire data set gave an r = (0.45579) with an (p = < 0.0001). The slopes for individual storms were all positive. This is shown in Figure 18 and in Table 14. This positive orientation

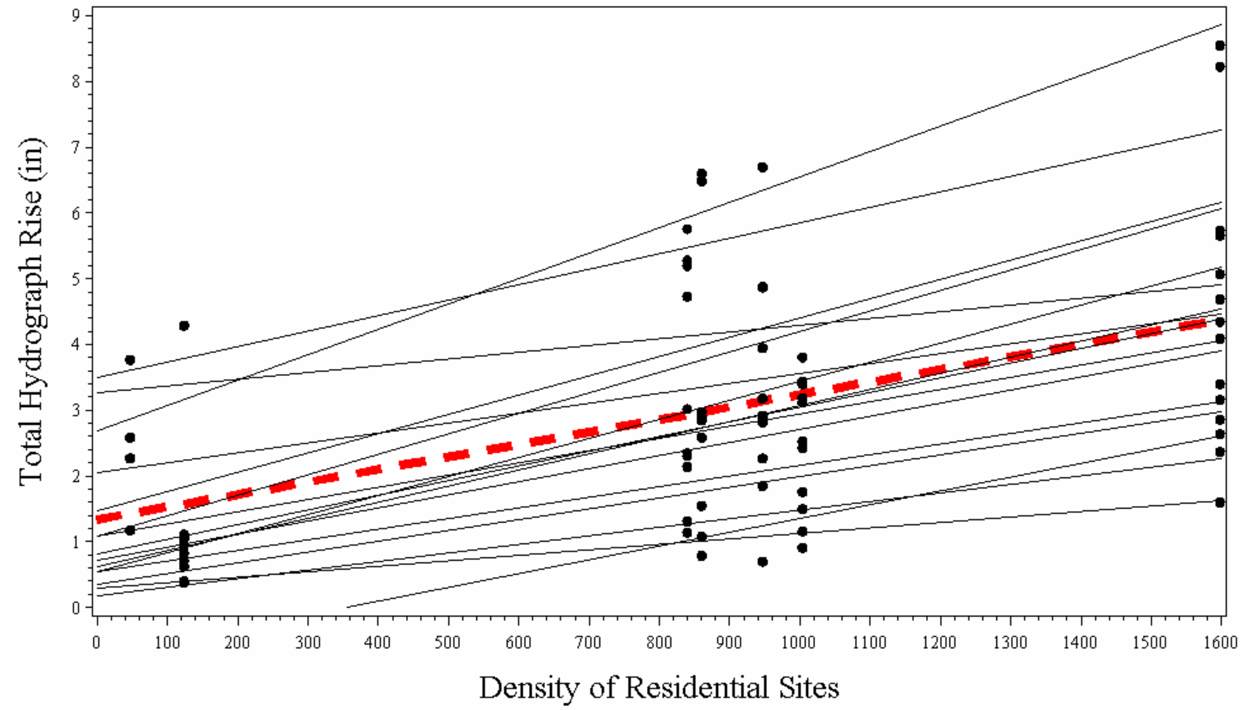

Figure 13. Total Hydrograph Rise as a Function of Residential Density. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 9: Statistics of Regressions of Total Hydrograph Rise as a Function of Residential Density

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	0.283943	0.00083	0.7299	0.5948	0.3765690	0.1457
11/14/1998	0.815386	0.00224	0.8958	0.8697	0.4014846	0.0042
12/10/1998	0.176274	0.00131	0.7781	0.6671	0.5183892	0.1179
12/12/1998	0.622741	0.00244	0.8894	0.7787	0.9040775	0.2159
12/23/1998	0.194147	0.00168	0.5101	0.3876	0.8642555	0.1108
12/28/1998	2.05600	0.00151	0.3277	0.1596	1.196131	0.2352
1/02/1999	1.07461	0.00312	0.7015	0.6269	1.070683	0.0374
1/22/1999	1.46512	0.00294	0.6145	0.4860	1.413440	0.1166
2/17/1999	0.344512	0.00165	0.6467	0.2934	0.6863347	0.4052
3/02/1999	0.719589	0.00199	0.8282	0.7709	0.5504778	0.0320
7/07/1999	0.533947	0.00290	0.2228	-0.5545	3.217742	0.6871
9/06/1999	-0.746148	0.00209	0.9669	0.9504	0.1687186	0.0167
12/18/1999	2.68761	0.00386	0.9717	0.9435	0.7225569	0.1075
12/20/1999	3.49642	0.00235	0.4262	0.1393	2.023010	0.3472
1/03/2000	1.08360	0.00185	0.9916	0.9831	0.1200177	0.0585
7/23/2000	3.26639	0.00103	0.1030	-0.1961	1.927368	0.5986
Avg. Slope of Storms	-	0.00163	-	-	-	-
All Data	1.29204	0.00191	0.2287	0.2174	0.0016278	< 0.0001

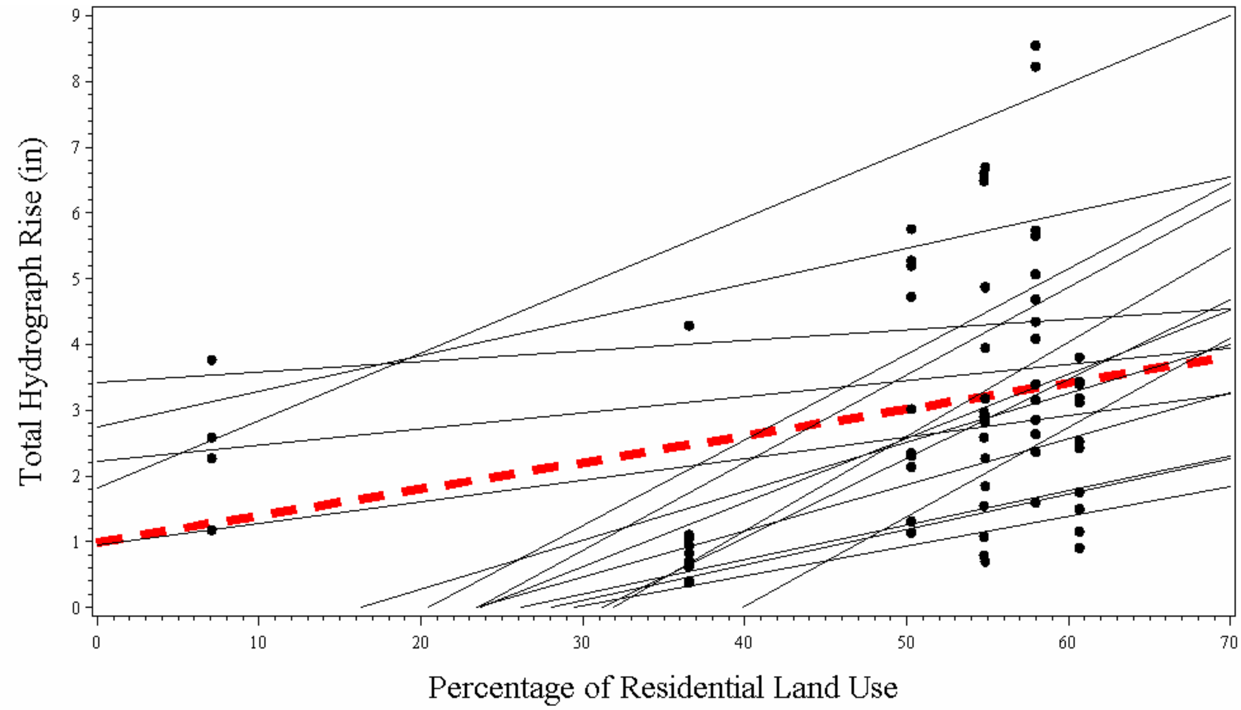

Figure 14. Total Hydrograph rise as a Function of Percentage of Residential Land Use. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 10: Statistics of Regression of Total Hydrograph Rise As a Function of Percentage of Residential Land Use

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	-0.3410	0.04552	0.7032	0.5548	0.394750	0.1614
11/14/1998	-2.3091	0.09761	0.5644	0.4555	0.820726	0.0851
12/10/1998	-1.3680	0.05227	0.4020	0.1029	0.850991	0.3660
12/12/1998	-4.5696	0.14326	0.9696	0.9392	0.473988	0.1116
12/23/1998	-1.6480	0.07020	0.5620	0.4160	0.679208	0.1446
12/28/1998	2.2180	0.02451	0.1434	-0.0708	1.35015	0.4592
1/02/1999	-3.1425	0.13346	0.4248	0.2810	1.48644	0.1608
1/22/1999	-2.6683	0.13030	0.3934	0.1912	1.77307	0.2574
2/17/1999	-5.4295	0.13606	0.8054	0.6108	0.509372	0.2909
3/02/1999	-3.7658	0.12062	0.9908	0.9877	0.127598	0.0004
7/07/1999	-1.2119	0.07437	0.0748	-0.8503	3.51063	0.8236
9/06/1999	-1.5159	0.05401	0.1013	-0.3481	0.879431	0.6818
12/18/1999	1.8092	0.10272	0.9285	0.8570	1.14895	0.1723
12/20/1999	2.7523	0.05428	0.0735	-0.3897	2.57062	0.7288
1/03/2000	0.94576	0.03300	0.9686	0.9373	0.231479	0.1133
7/23/2000	3.4275	0.01601	0.0377	-0.2831	1.99625	0.7544
Avg. Slope of Storms	-	0.07267	-	-	-	-
All Data	0.99164	0.04043	0.0792	0.0654	1.83485	0.0192

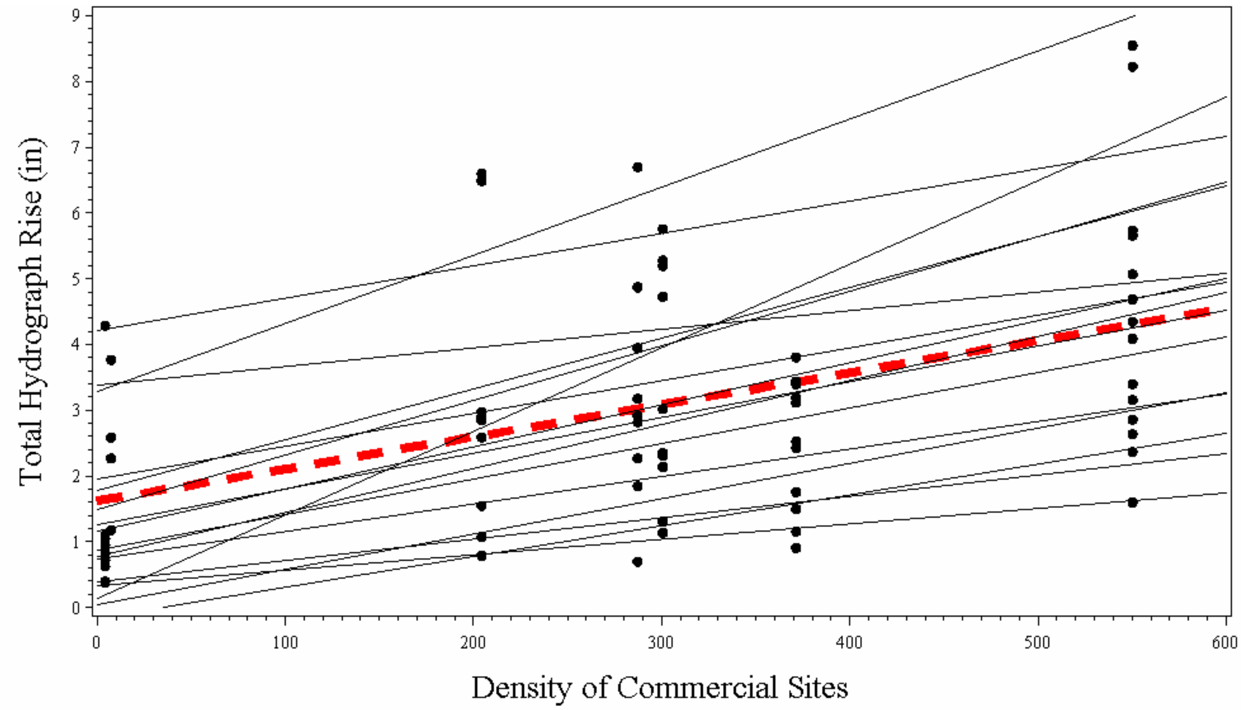

Figure 15. Total Hydrograph Rise as a Function Commercial Density. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 11: Statistics of regressions of Total Hydrograph Rise as a Function of Commercial Density

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	0.334009	0.00236	0.8235	0.7353	0.304369	0.0925
11/14/1998	1.26094	0.00544	0.7806	0.7257	0.582473	0.0196
12/10/1998	0.392877	0.00324	0.6752	0.5128	0.627123	0.1783
12/12/1998	0.779831	0.00668	0.9368	0.8737	0.683050	0.1617
12/23/1998	0.737999	0.00419	0.8642	0.8189	0.378245	0.0222
12/28/1998	1.95874	0.00497	0.4688	0.3360	1.06318	0.1334
1/02/1999	1.49776	0.00827	0.7281	0.6601	1.02202	0.0307
1/22/1999	1.77634	0.00773	0.5970	0.4626	1.44529	0.1256
2/17/1999	0.048150	0.00536	0.7134	0.4268	0.618131	0.3596
3/02/1999	0.878582	0.00541	0.8579	0.8105	0.500654	0.0238
7/07/1999	0.140847	0.01271	0.5544	0.1089	2.43627	0.4653
9/06/1999	-0.165605	0.00468	0.8155	0.7233	0.398411	0.0969
12/18/1999	3.27749	0.01037	0.8798	0.7596	1.49004	0.2254
12/20/1999	4.21016	0.00492	0.2774	-0.0839	2.27026	0.4733
1/03/2000	1.16660	0.00639	0.9873	0.9745	0.147500	0.0720
7/23/2000	3.38572	0.00282	0.0981	-0.2025	1.93257	0.6078
Avg. Slope of Storms	-	0.00597	-	-	-	-
All Data	1.61866	0.00488	0.2168	0.2051	1.69216	<. 0001

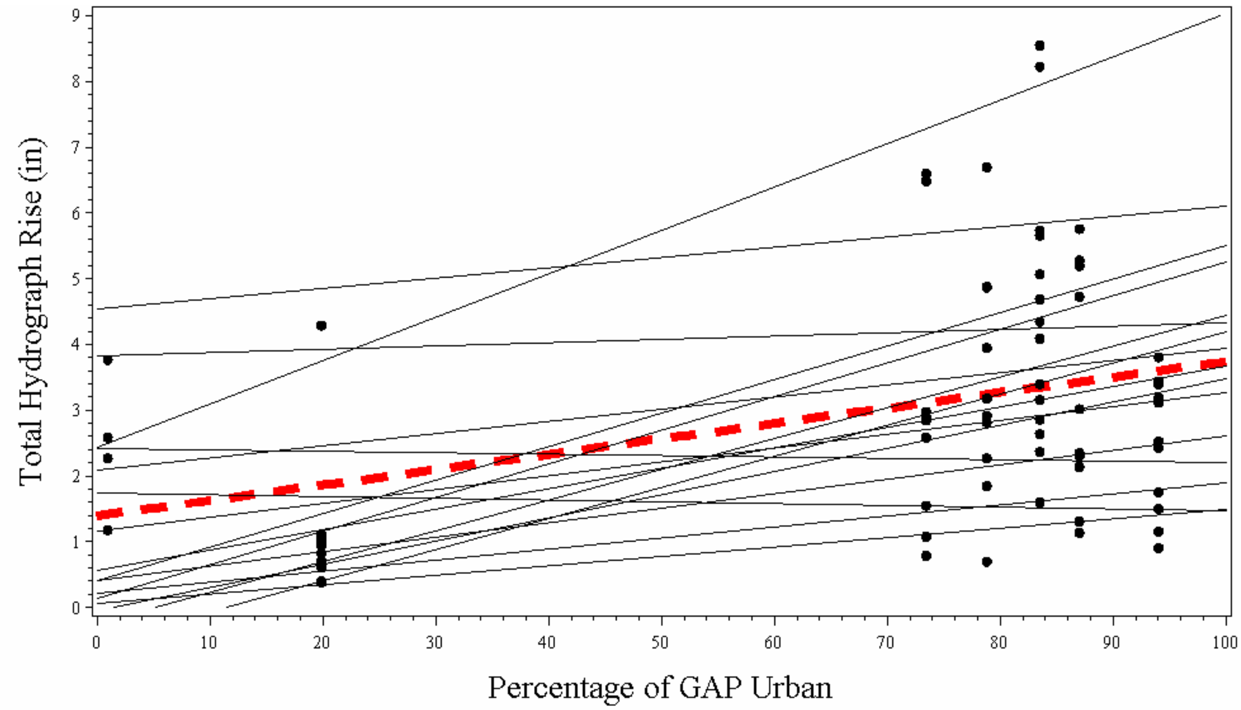

Figure 16. Total Hydrograph Rise as a Function of Percentage of GAP Urban. Dashed red line represents regression of entire data set, solid lines represent individual storms.

Table 12: Statistics of Regressions of Total Hydrograph Rise as a Function of Percentage of GAP Urban

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	0.064736	0.01426	0.6486	0.4730	0.429496	0.1946
11/14/1998	0.553232	0.03112	0.5644	0.4555	0.820670	0.0851
12/10/1998	0.214829	0.01683	0.3916	0.0874	0.858331	0.3742
12/12/1998	-0.243547	0.04690	0.9588	0.9176	0.551665	0.1302
12/23/1998	0.411159	0.02198	0.5511	0.4014	0.687598	0.1508
12/28/1998	2.09042	0.01859	0.2398	0.0497	1.27187	0.3242
1/02/1999	0.143142	0.05117	0.6146	0.5182	1.21673	0.0650
1/22/1999	0.411706	0.05101	0.6032	0.4700	1.43401	0.1223
2/17/1999	2.4101	-0.00200	0.0002	-0.9997	1.15457	0.9916
3/02/1999	-0.05149	0.035335	0.8508	0.8011	0.512969	0.0257
7/07/1999	-0.542954	0.04729	0.4231	-0.1538	2.77219	0.5491
9/06/1999	1.74654	-0.00286	0.0010	-0.4984	0.927173	0.9677
12/18/1999	2.44336	0.06591	0.9546	0.9093	0.915338	0.1366
12/20/1999	4.53554	0.01575	0.0568	-0.4148	2.59375	0.7617
1/03/2000	1.15205	0.02110	0.9862	0.9724	0.153511	0.0749
7/23/2000	3.82390	0.00500	0.0105	-0.3194	2.02429	0.8700
Avg. Slope of Storms	-	0.02888	-	-	-	-
All Data	1.39252	0.02344	0.1289	0.1159	1.78459	0.0024

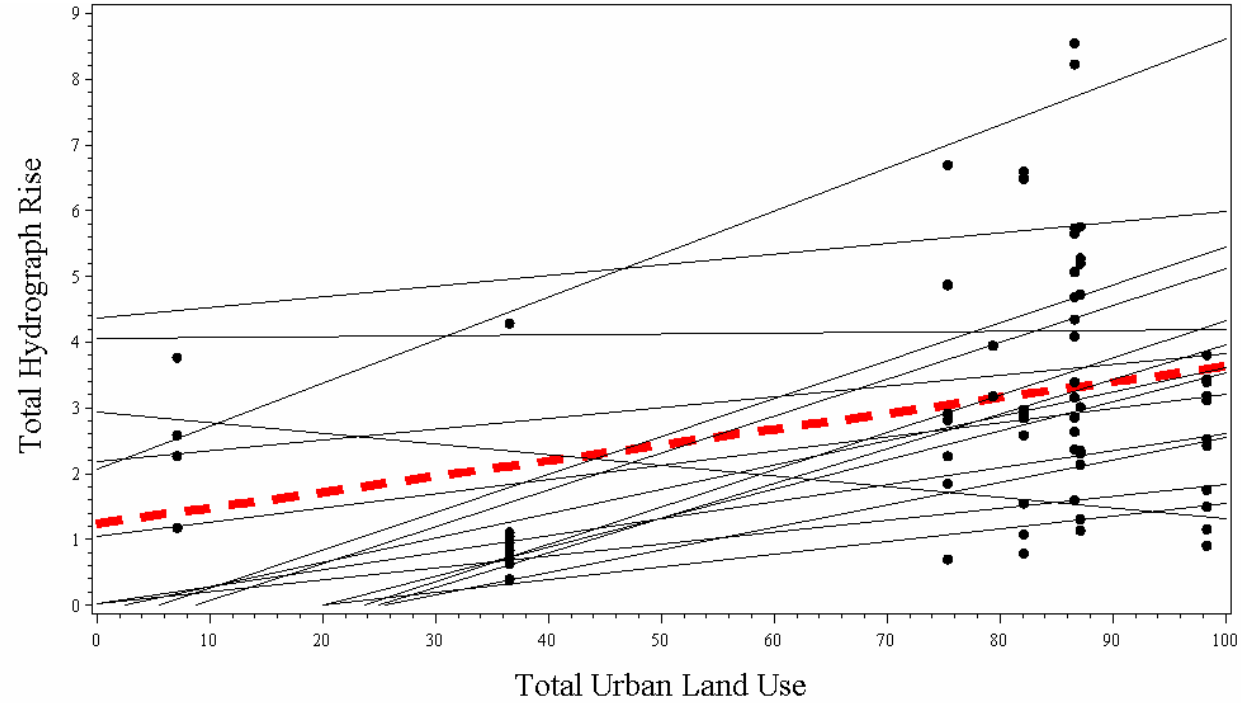

Figure 17. Total Hydrograph Rise as a Function of Total Urban Land Use. Dashed red line represents a regression of entire data set, solid lines represent individual storms.

Table 13. Statistics of Regressions of Total Hydrograph Rise as a Percentage of Total Urban Land Use

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	-0.38811	0.01937	0.7702	0.6553	0.34736	0.1224
11/14/1998	-0.09490	0.03718	0.5153	0.3941	0.86571	0.1082
12/10/1998	0.02873	0.01817	0.2937	-0.0594	0.92841	0.4580
12/12/1998	-1.34550	0.05672	0.9377	0.8753	0.67856	0.1606
12/23/1998	0.02059	0.02587	0.4848	0.3130	0.73664	0.1915
12/28/1998	2.17515	0.01647	0.1749	-0.0313	1.32504	0.4092
1/02/1999	-0.49305	0.05613	0.4740	0.3425	1.42137	0.1304
1/22/1999	-0.31697	0.05774	0.4905	0.3207	1.62499	0.1878
2/17/1999	-0.87583	0.03428	0.0772	-0.8456	1.10294	0.8207
3/02/1999	-0.89091	0.04435	0.8507	0.8010	0.51308	0.0257
7/07/1999	-1.32036	0.05277	0.3245	-0.3510	2.99980	0.6142
9/06/1999	2.93651	-0.01616	0.0217	-0.4675	0.91754	0.8527
12/18/1999	2.07487	0.06547	0.9257	0.8514	1.17156	0.1758
12/20/1999	4.36574	0.01629	0.0410	-0.4385	2.61534	0.7975
1/03/2000	1.04862	0.02153	0.9336	0.8671	0.33689	0.1660
7/23/2000	4.05668	0.00135	0.0007	-0.3324	2.03427	0.9667
Avg. Slope of Storms	-	0.03172	-	-	-	-
All Data	1.23859	0.02396	0.1021	0.0887	1.81181	0.0074

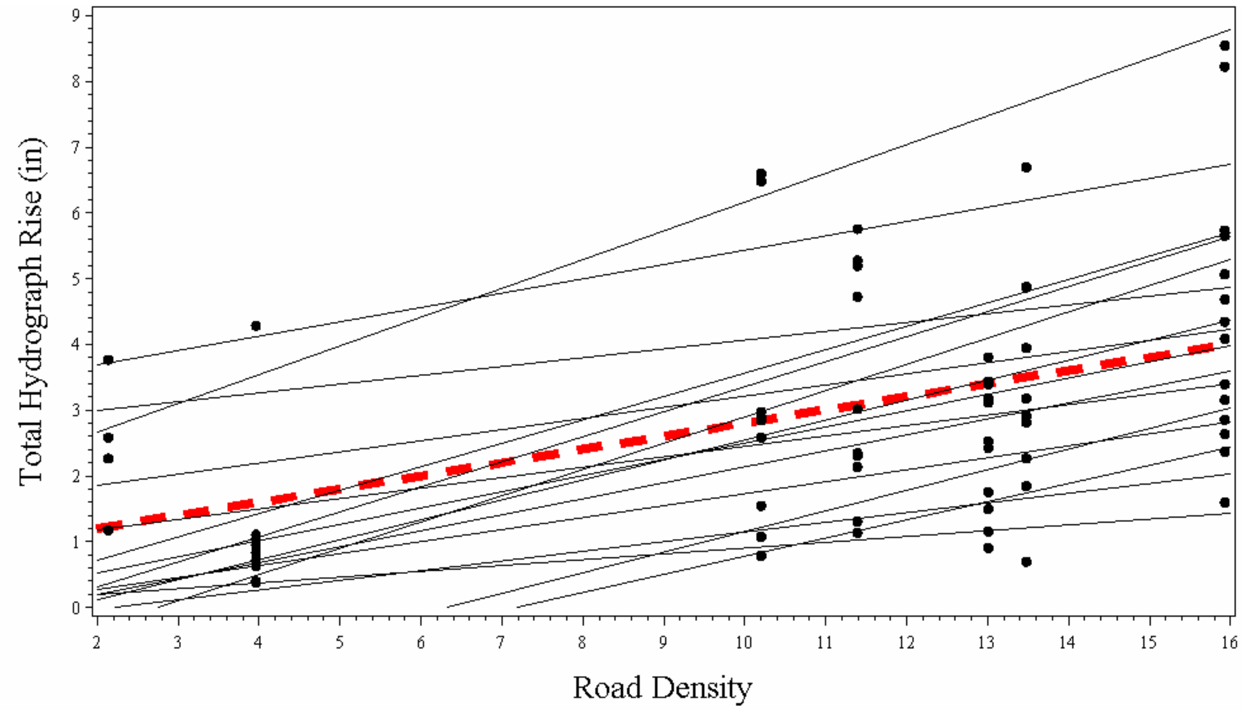

Figure 18. Total Hydrograph Rise as a function of Road density. Dashed red line represents a regression of entire data set, solid line represents individual storms.

Table 14: Statistics of Regressions of Total Hydrograph Rise as a Function of Road Density

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	0.02167	0.08867	0.6184	0.4275	0.447618	0.2136
11/14/1998	0.02164	0.24681	0.8286	0.7858	0.514797	0.0117
12/10/1998	-0.32802	0.14707	0.7374	0.6062	0.563865	0.1413
12/12/1998	-0.49071	0.30394	0.9735	0.9470	0.442392	0.1041
12/23/1998	-0.09269	0.18177	0.8639	0.8186	0.378556	0.0222
12/28/1998	1.5271	0.16849	0.3795	0.2244	1.14905	0.1928
1/02/1999	-0.44164	0.38036	0.7922	0.7403	0.893349	0.0175
1/22/1999	0.00331	0.35605	0.6735	0.5647	1.30082	0.0887
2/17/1999	-1.9894	0.31405	0.7827	0.5655	0.538197	0.3087
3/02/1999	-0.29826	0.24352	0.9260	0.9013	0.361306	0.0087
7/07/1999	-1.1034	0.39938	0.3813	-0.2374	2.87091	0.5763
9/06/1999	-1.9851	0.27621	0.8183	0.7275	0.395408	0.0954
12/18/1999	1.8003	0.43637	0.9901	0.9803	0.426749	0.0633
12/20/1999	3.2539	0.21790	0.2606	-0.1091	2.29649	0.4895
1/03/2000	0.87434	0.15749	0.9890	0.9781	0.136821	0.0668
7/23/2000	2.7304	0.13334	0.1561	-0.1251	1.86935	0.5103
Avg. Slope of Storms	-	.18636	-	-	-	-
All Data	0.79825	0.20053	0.2077	0.1959	1.70194	< 0.0001

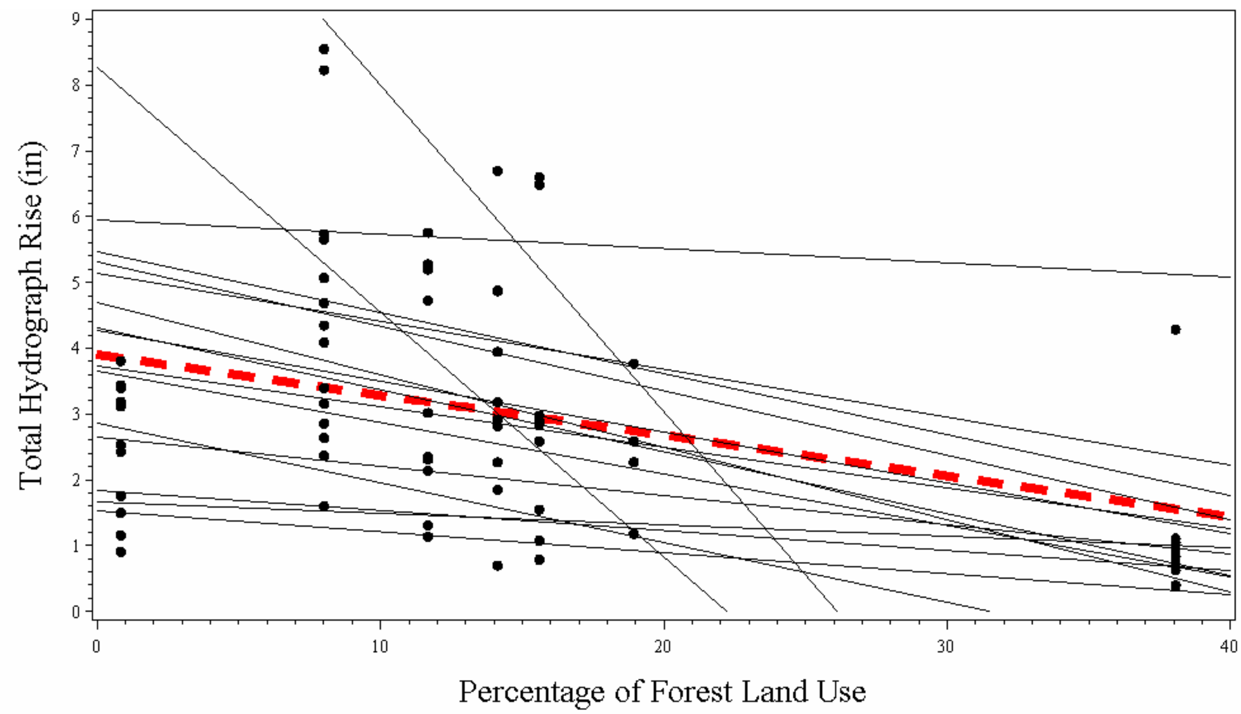

Figure 19. Total Hydrograph rise as a function of Percentage of Forest Land Use. Dashed red line represents regression of entire data set, solid lines represent individual Storms.

Table 15: Statistics of regressions of Total Hydrograph Rise as a function of Percentage of Forest Land Use

Stormid	Regression Constant	Slope	R-squared	Adjusted R-squared	Standard Error	Pr > F
11/10/1998	1.53631	-0.03185	0.7555	0.6333	0.358260	0.1308
11/14/1998	3.73142	-0.06200	0.4930	0.3662	0.885438	0.1199
12/10/1998	1.84079	-0.03034	0.2973	-0.0541	0.922471	0.4548
12/12/1998	4.31605	-0.09414	0.9360	0.8721	0.687408	0.1628
12/23/1998	2.65336	-0.04435	0.4933	0.3244	0.730516	0.1860
12/28/1998	4.27561	-0.07718	0.1435	-0.0706	1.35001	0.4589
1/02/1999	5.31475	-0.09822	0.4980	0.3725	1.38861	0.1172
1/22/1999	5.46088	-0.09229	0.4340	0.2453	1.71275	0.2266
2/17/1999	2.85357	-0.09059	0.3743	-0.2513	0.913327	0.5809
3/02/1999	3.65580	-0.07834	0.9189	0.8919	0.378176	0.0101
7/07/1999	4.70346	-0.11032	0.3704	-0.2592	2.89606	0.5835
9/06/1999	1.66409	-0.01760	0.0213	-0.4680	0.917716	0.8540
12/18/1999	12.9514	-0.49587	0.8354	0.6707	1.74370	0.2660
12/20/1999	5.94098	-0.02165	0.0256	-0.4616	2.63623	0.8399
1/03/2000	8.27037	-0.37210	0.9849	0.9697	0.160743	0.0785
7/23/2000	5.14672	-0.07301	0.0291	-0.2946	2.00518	0.7840
Avg. Slope of Storms	-	-.01546	-	-	-	-
All Data	3.90299	-0.06161	0.1324	0.1195	1.78100	0.0021

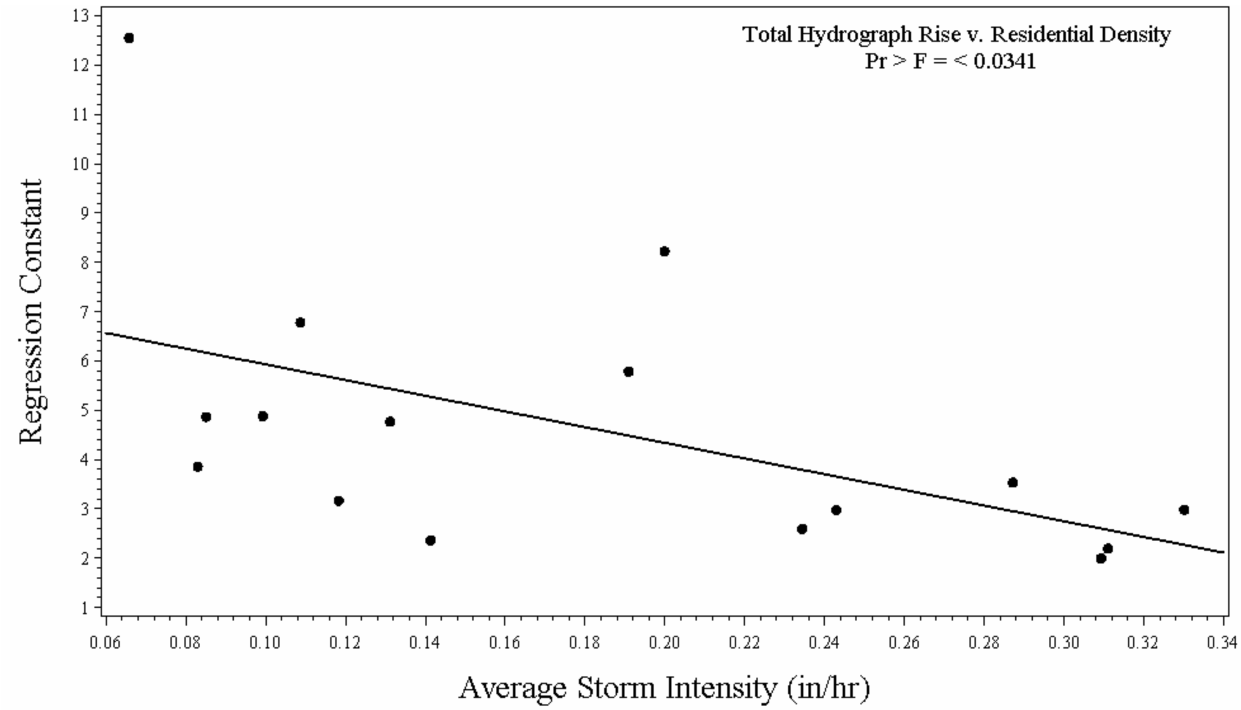

Figure 20. Regression constant as a Function of Average Storm Intensity.

of the slopes indicates that as road density in a watershed increases so does the total rise in stage height. Road density again proves to be a good indicator of urban development.

Total rise in stage height is regressed against the percentage of forest land use resulting in a significant regression. The entire data set gave an r = -0.36390 (p = 0.0021). The slopes were all negative for the regressions on individual storms. This demonstrates that the more forest land use in a watershed, the less total rise will occur for a given storm event. These relationships are demonstrated in Figure 19 and Table 15. This is important for planners to recognize and incorporate into land use and zoning policy. It is important to note that the percentage forest canopy did not result in a significant relationship to total rise. The percentage of forest canopy includes forest and those areas with greater than 50 percent canopy closure with urban land uses. This is an area described as an urban forest.

In the regressions mentioned in this section the slopes for the individual storms were consistent. In the summary statistics it can be seen that the average slopes are quite close in comparison with the slope of the entire data set. The regression constant, however, varies from storm to storm. This can possibly be explained by the difference in average storm volume (acre feet) produced by the individual storms. These relationships are shown in Figures 20 through 26.

4.3 Predictive Models Based on Multiple Regression

Initially, All land use and cover characteristic variables were evaluated using a stepwise multiple regression technique. This approach suggested several candidate models. In a second step regressors were chosen based on observations and knowledge of watershed behavior. These were compared using their R^2 and Standard error statistics. For time to rise the following model was chosen. It resulted in a $R^2 = 0.4598$ with a standard error of 1.3432. This model can be used by planners to predict the effects of further development and canopy reduction on time to rise in these watersheds.

Equation (1) $TR = 4.99405 + 0.4325 * F - 0.01868 * RL - 0.05419 * T$

Where: TR = Time to Rise in hours

F = Area of Forest Land Cover in square miles (> 50% canopy closure)

Rl = Road Length in miles

T = Percent of Transition Canopy (10% - 50% canopy closure)

The same approach was used to generate a model for total rise in stage. The following model was chosen. The model has a $R^2 = 0.2764$ and a standard error = 1.63883. This model will give planners a tool to estimate the effect of future development on total rise in stage for a given storm.

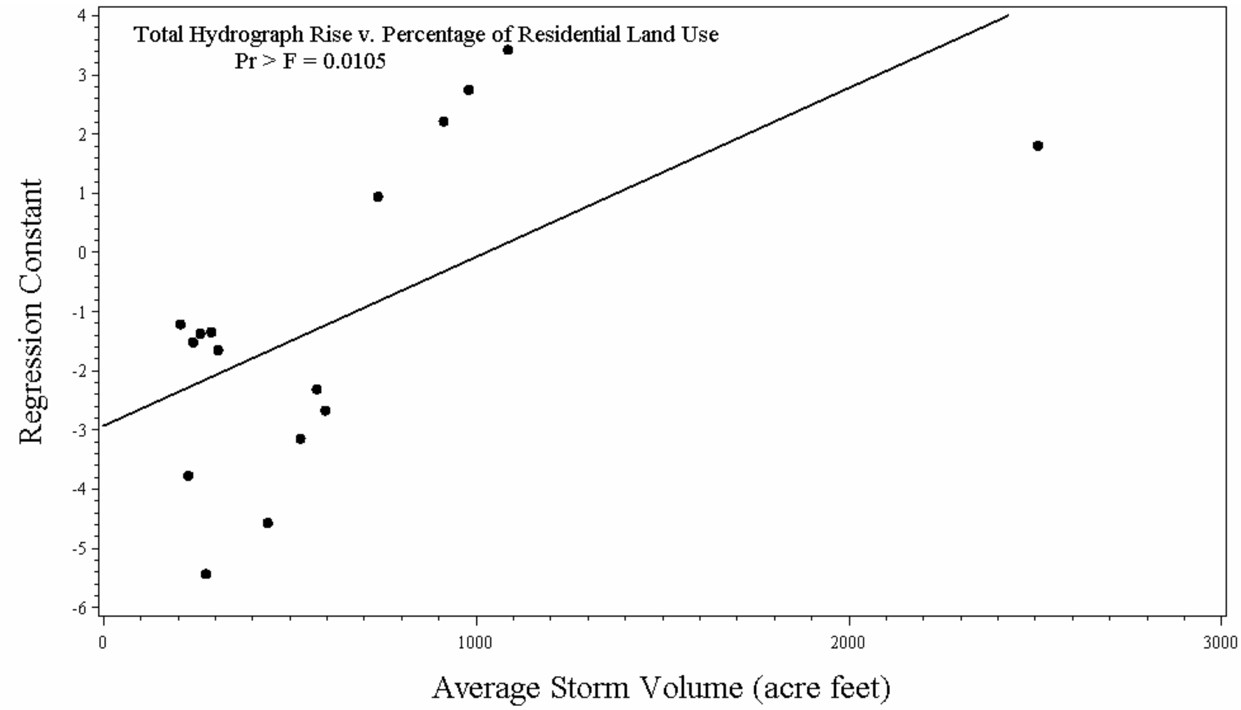

Figure 21. Regression Constant as a function of Average Storm Intensity.

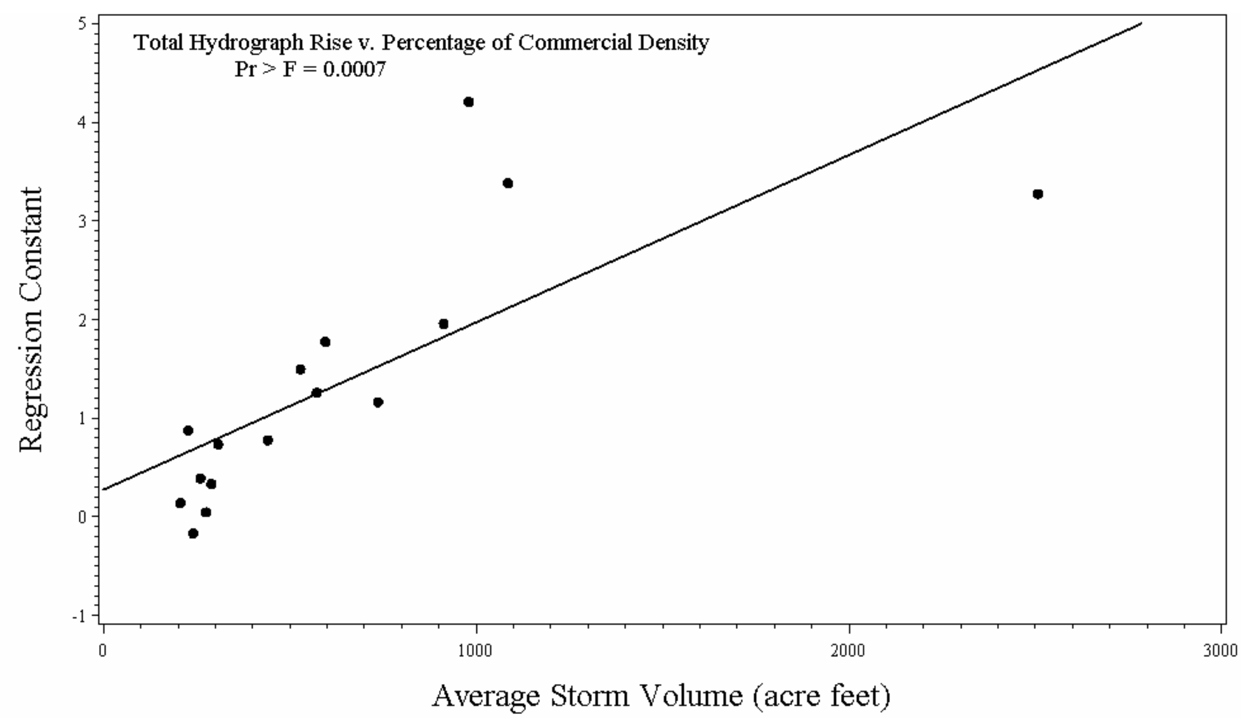

Figure 22. Regression Constant as a Function of Average Storm Volume.

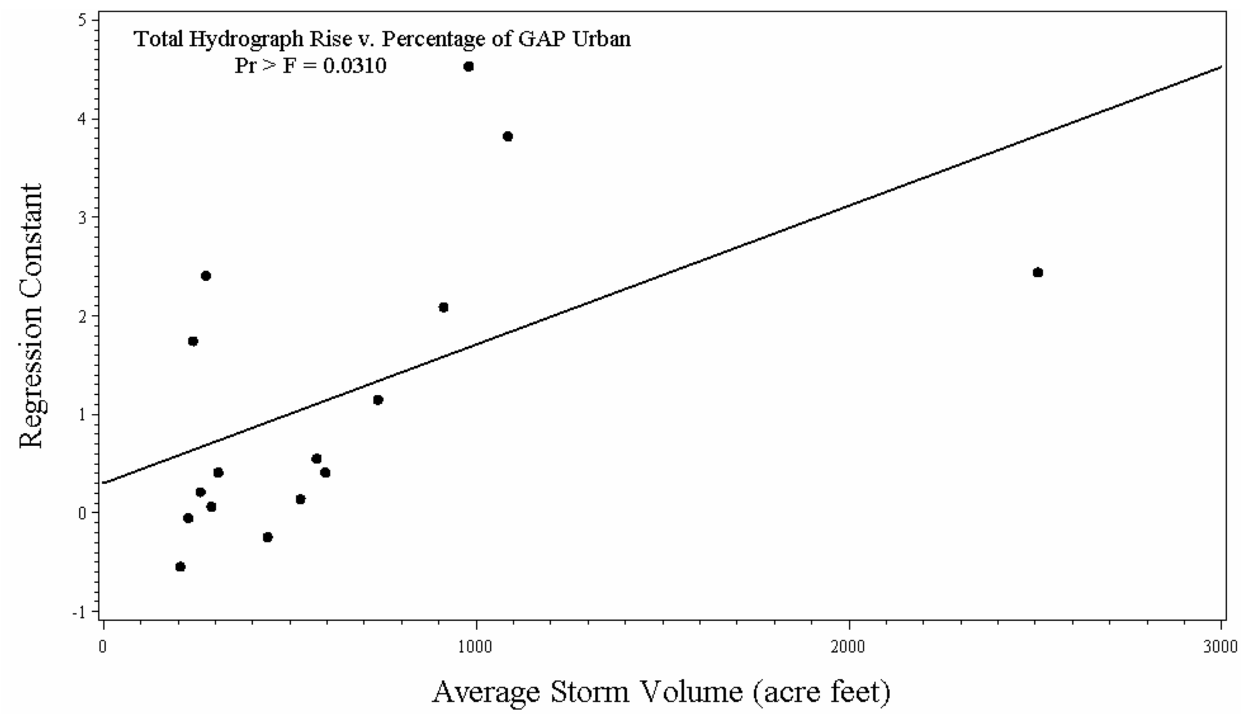

Figure 23. Regression Constant as a Function of Average Storm Volume.

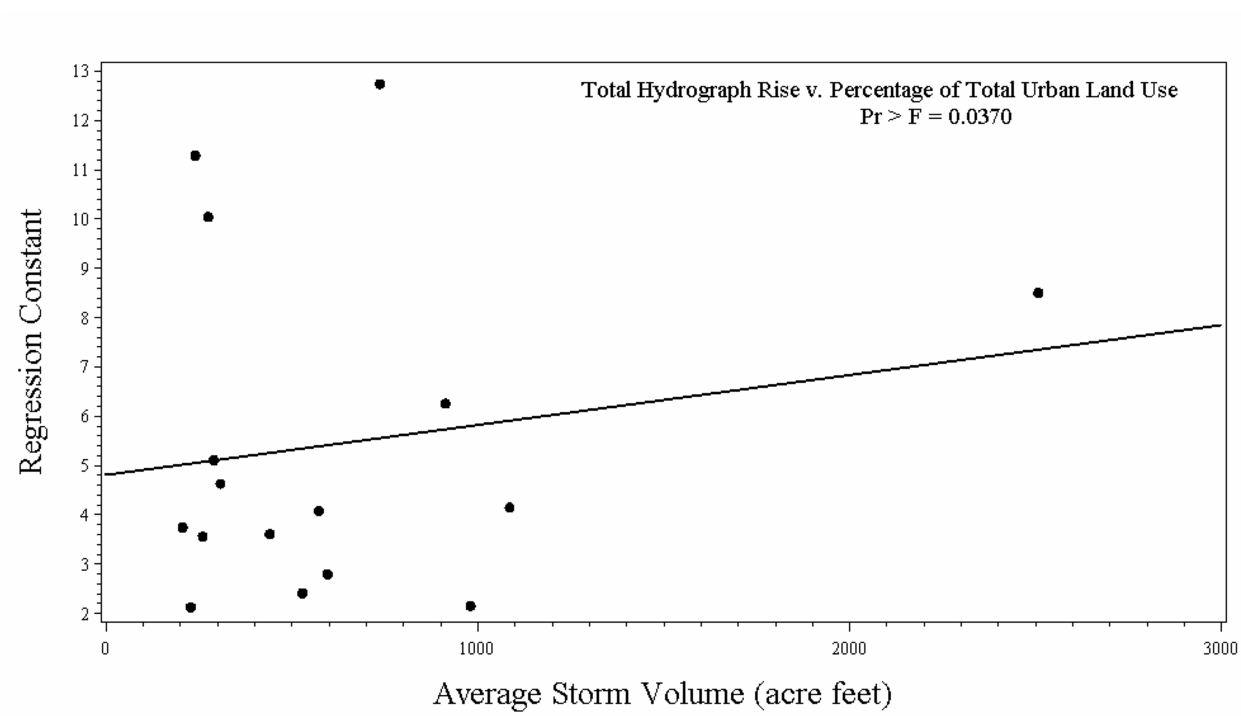

Figure 24. Regression Constant as a Function of Average Storm Volume.

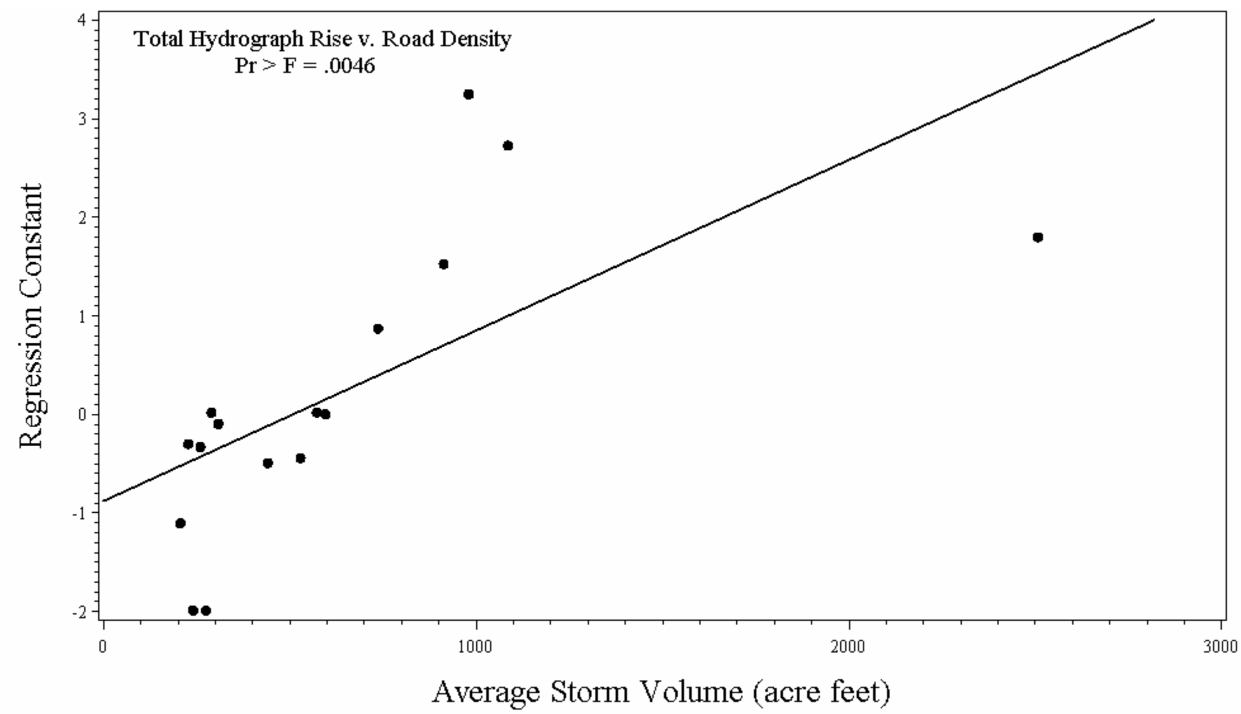

Figure 25. Regression Constant as a Function of Average Storm Volume.

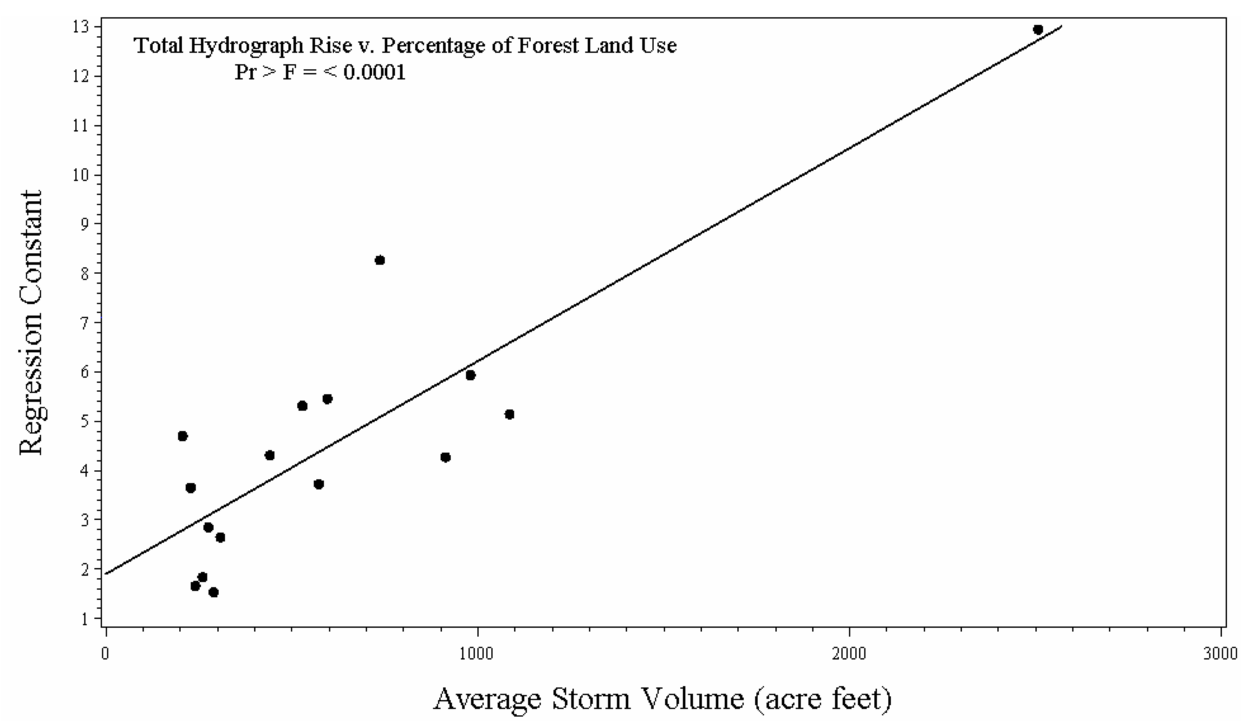

Figure 26. Regression Constant as a Function of Average Storm Volume.

$$\text{Equation (2) } TRS = 0.89707 + 0.01107 * RL + 0.04412 * GVU$$

Where: TRS = Total Rise in Stage in (in.)

RL = Road Length in Miles

GVU = Percentage of GAP Vegetated Urban

5 Summary and Conclusions

Hydrograph and precipitation data were examined for seven watersheds in East Baton Rouge Parish. This was done to determine if consistent patterns could be established between land use and land cover characteristics and their resulting effects on the hydrograph response. Specifically, time to hydrograph rise and total rise in hydrograph stage. The study first established a GIS database of land use and land cover characteristics. The second phase performed regression analyses of the response variables with the land use and land cover characteristics as independent variables. These analyses resulted in the development of models that can be used in the urban planning process.

There were statistically significant relationships between residential development and the response variables, time to rise and total rise. As the amount of residential development increases, the time to rise for a watershed decreases. At the same time the total rise in stage height increases. This can be explained by an increase in impervious surfaces and a decrease of vegetation associated with residential development. Rooftops, driveways, and residential streets are all examples of impervious surfaces. Impervious surfaces have been shown by Booth and Leavitt (1999) to disrupt the natural water runoff system by taking away the water retaining function of the soil. It has also been demonstrated by Putnam (1972) to speed up runoff. He concludes that quicker the water runs off the watershed greater the flood magnitude. The results of this study indicated increases in residential development resulted in both quicker and greater amounts of runoff. This suggests a need for regulations limiting the number of housing units in a watershed, and onsite controls, such as detention and retention ponds, to detain or retain runoff.

There were strong relationships evident between commercial development and the response variables as well. These results suggest that increasing commercial development in a watershed decreases the time a hydrograph rises and increases its total rise. This, again, is due to the increase in impervious surfaces (Booth and Leavitt, 1999). Commercial land uses are nearly 100 percent impervious surface. This completely alters the natural runoff system. Instead of water infiltrating into the soil and absorbed, it becomes direct runoff. Thus all of the precipitation becomes overland flow. Developers must limit the amount of runoff they produce and export to downstream locations. Several techniques can be applied to address this problem. These include the installation of pervious surface parking lots, retention ponds and detention ponds (Arnold & Gibbons, 1996; Losco, 1994).

When residential and commercial development are combined, the effect of total urban land use can be observed. These factors show a strong association to both time to rise and total rise. This indicates that watershed runoff behavior can be directly linked to urban development. These results strongly support the conclusion that urban development has a negative impact on the natural hydrologic system. It disrupts the hydrologic cycle by shortcutting the absorption of water by the soil column and produces abnormally large volumes of runoff. This suggests that it is important to consider regulating development at the watershed level. This can only be addressed through land use planning. This ultimately can be achieved by establishing better zoning requirements for all development.

Road density was highly correlated to both time to rise and total rise. As roads increase in a watershed, storm hydrographs show a decrease in time to rise and an increase in total rise. In this study, roads proved to be a very good indicator of urban development. Roads not only produce runoff as impervious surface but also are often designed to directly feed in to streams through, storm drains, ditching and curbing. This land use characteristic is one of the easiest to determine for a watershed and deserves further investigation into its potential as a component in planning models.

The percentage of forest land use, land maintained as contiguous forest, was correlated with total rise but not time to rise. As the percentage of forest land use increased the total rise decreased. The importance influence of forest is the vegetation's interception and evapotranspiration capabilities Hewlett, 1982). The soil column in forests also has more water absorbing capacity. Forest maintains a natural system, which produces less direct runoff, than developed sites. This suggests that planners should try to maintain as much-undisturbed forestland as possible. It is understandably difficult to both develop areas and maintain forest. However, leaving forest corridors could be a cost effective alternative to complete deforestation. Ultimately, savings can be gained by avoiding costly flood losses.

The percentage of forest canopy, the percentage of land covered by 50 percent or greater canopy closure, could not be correlated to either response variable. Forest canopy could play a role in slowing the runoff process, but watersheds could reach a level of impervious surface at which its effect is negligible. It should be noted that this data represents a classification system. The system of classifying the canopy was arbitrary (East Baton Rouge Parish Tree Commission, 1995). To better study the affects of the canopy, an actual measure of the percent canopy should be taken for each forest stand in the watershed.

This study demonstrates some univariate models that show direct relationships between land use and land cover characteristic and hydrograph response. These relationships are highly statistically significant with reasonably high correlations. They may be used by planners to determine the effect of adding another residential development, commercial unit, or road to a watershed. The multivariate model explains nearly 46 percent of the predictability in time to rise with road length, area of forestland use, and percent of transition canopy. The development of a multivariate model for total rise was not as successful, only explaining 28 percent of the variability due to road length and percentage of GAP vegetated urban. The production of these models was limited by multicollinearity. The complex mosaic of land use and land cover patterns creates a great deal of correlation between independent variables. .

The lack of a control for hydromodification is a source of potential error in this study. In South LA, it is common for runoff to be diverted out of its natural watershed into another through man-made drainage projects. A second source of error and uncertainty is the derivation of residential and commercial land uses. This was not done using precise, lot level surveying techniques to determine areas. It was accomplished by roughly cutting out the areas from the watershed, using heads-up digitizing in the GIS. In determining the densities of residential and commercial sites the number of sites was divided into the area. The density could be more accurately calculated if the area of each site was known. Ideally the actual area of impervious surface should be defined.

Future studies could be improved by using spatially distributed precipitation data across each watershed. This would result in more accurate precipitation data instead of relying on the rain gauges at the storm gauge and assuming precipitation was uniform across the entire watershed. If the stream discharge was available, a better understanding of the rainfall runoff relationship could be established. Understanding and being able to predict the relationship between urbanization and the hydrograph response needs further research.

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Appendix A: Data Layers

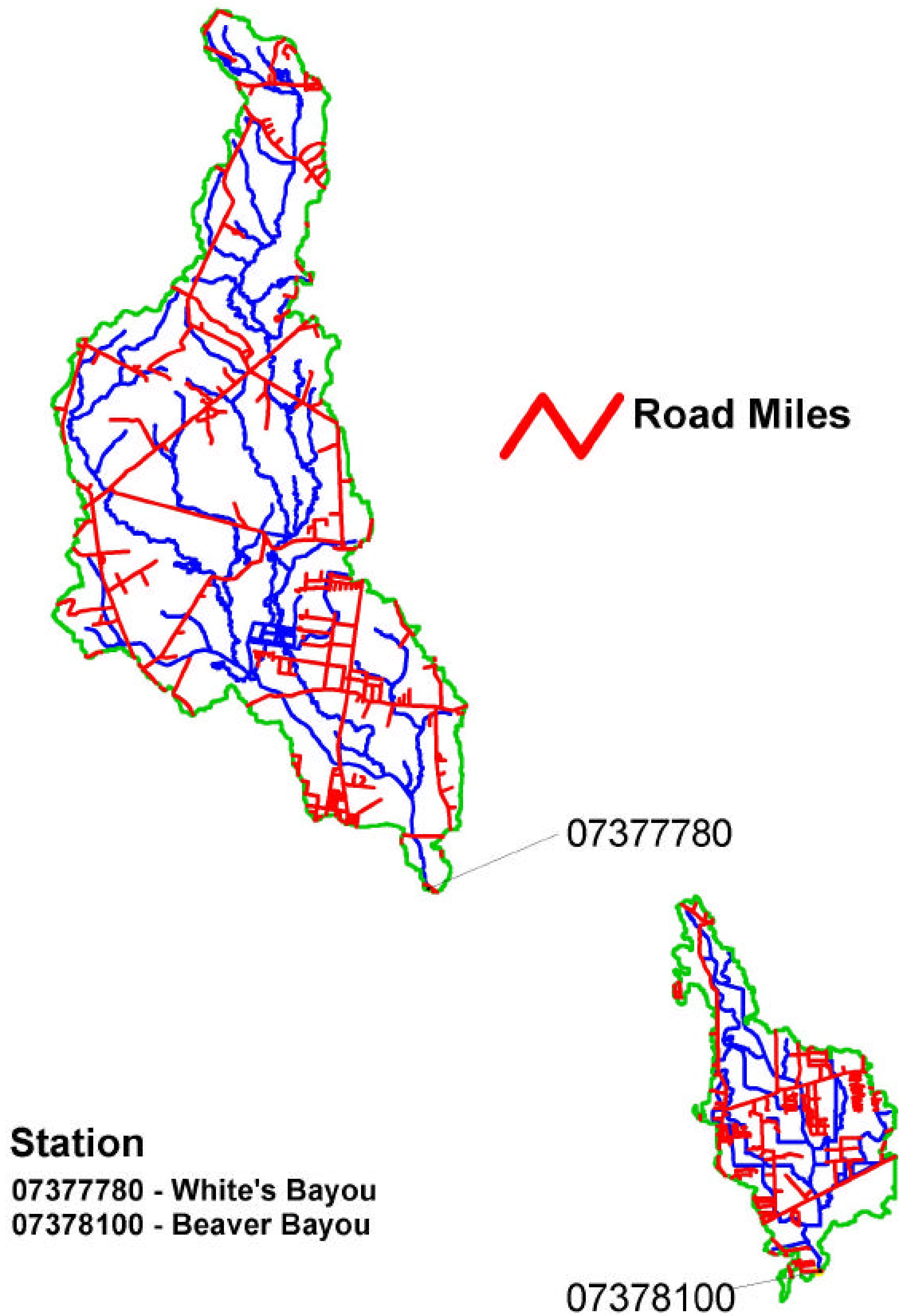

Figure A-1: Rural Watershed's Road Data Layer.

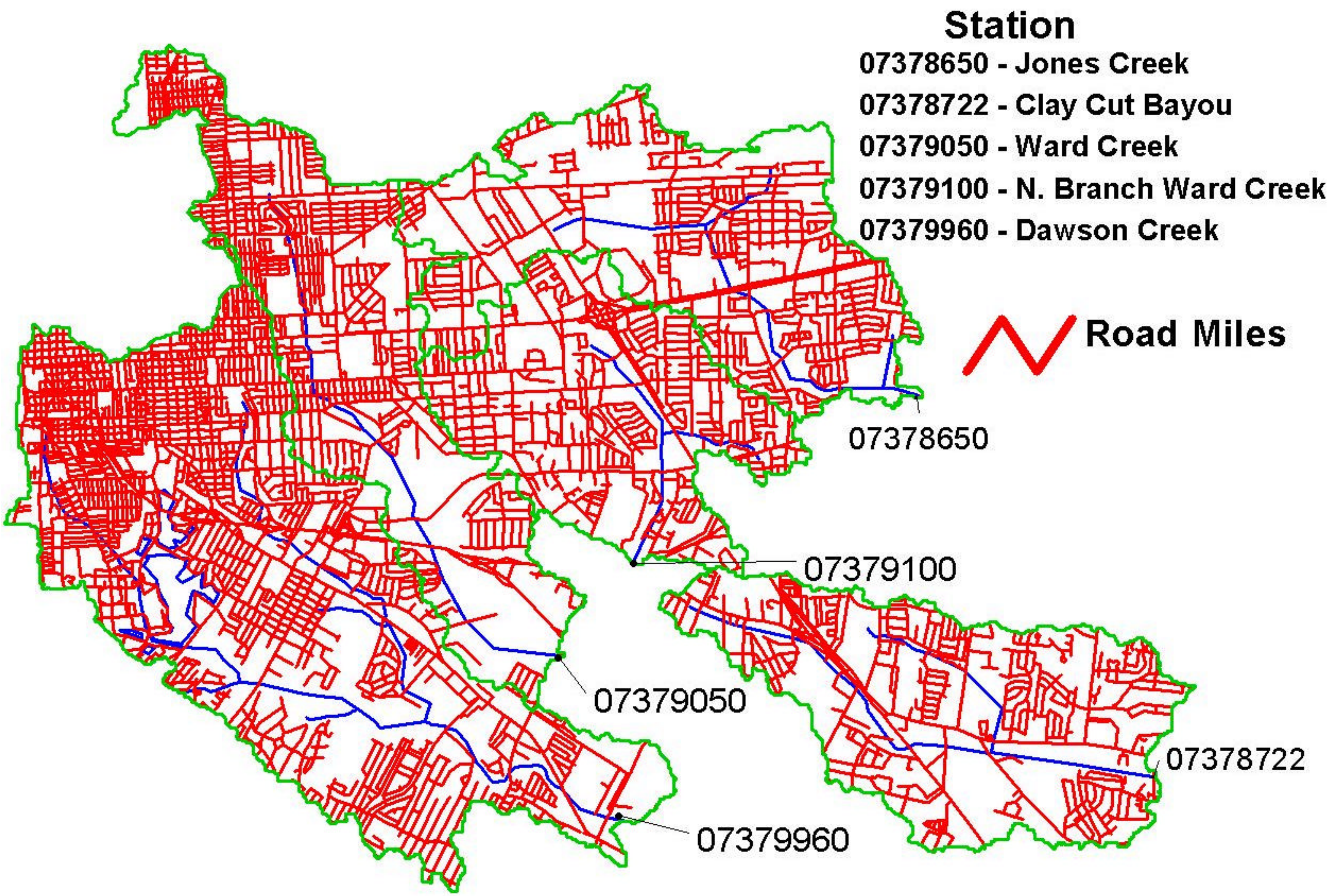

Figure A-2: Urban Watershed's Road Data Layer.

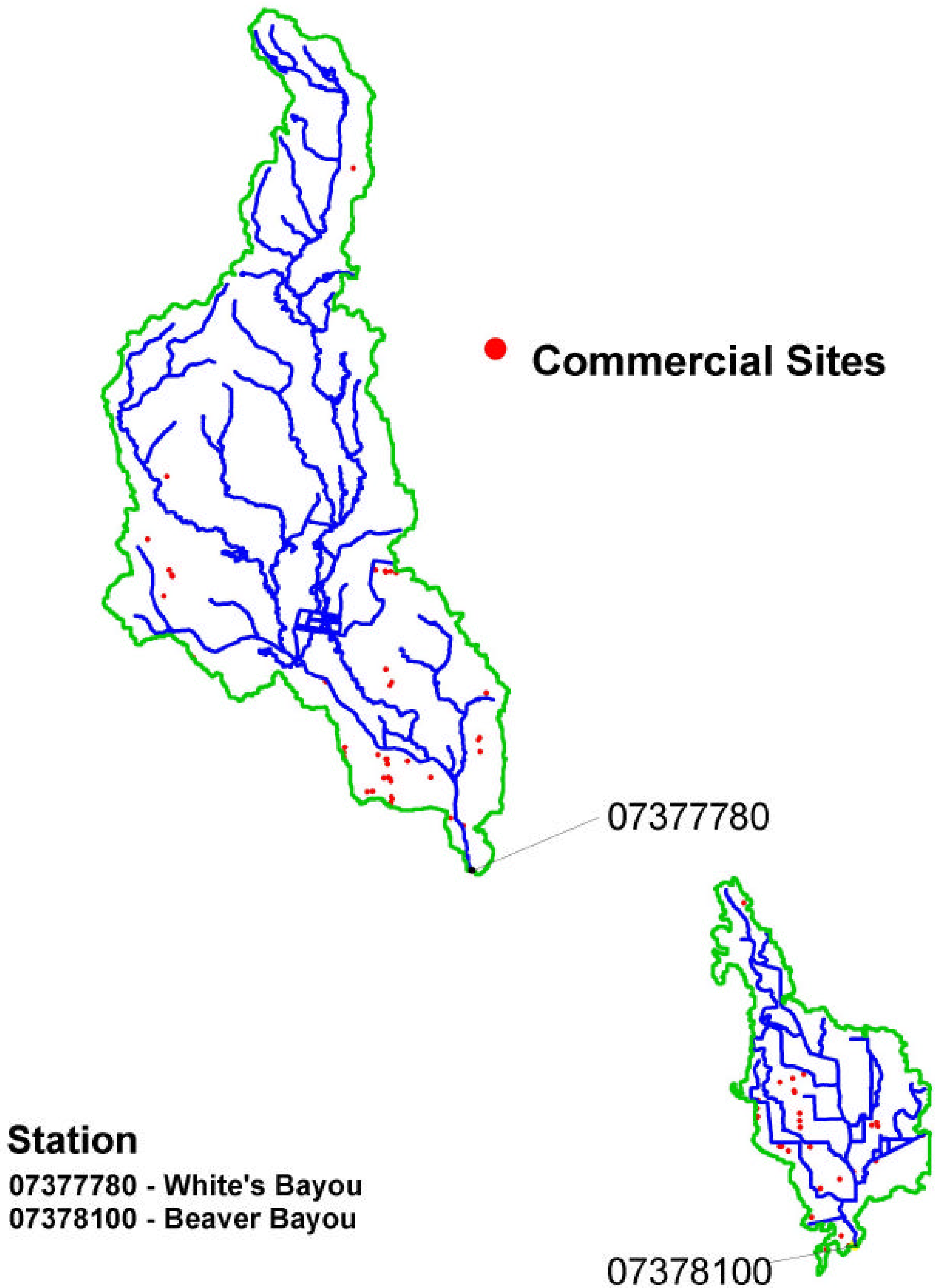

Figure A-3: Rural Watershed's Commercial Data Layer.

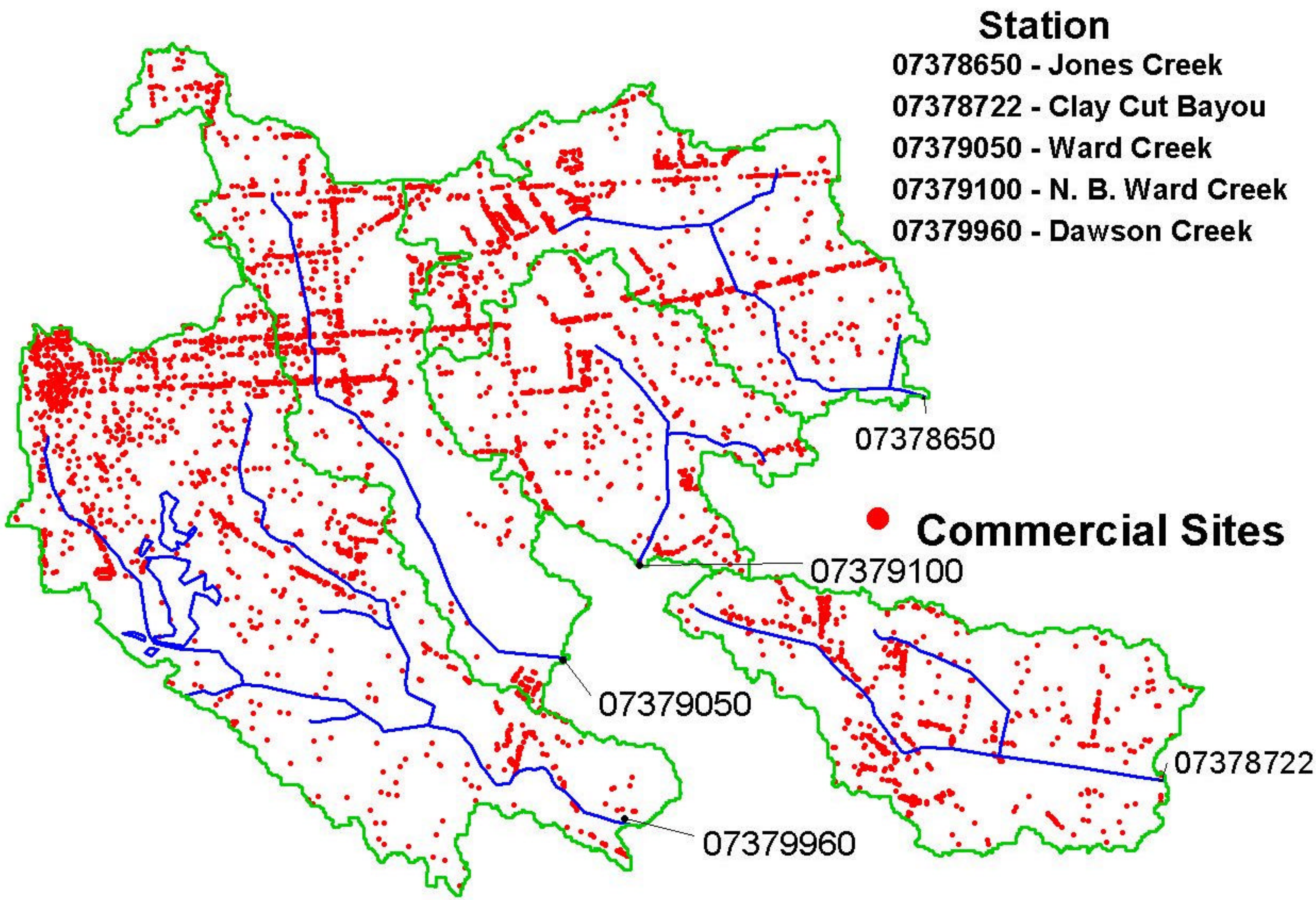

Figure A-4: Urban Watershed's Commercial Sites Data Layer.

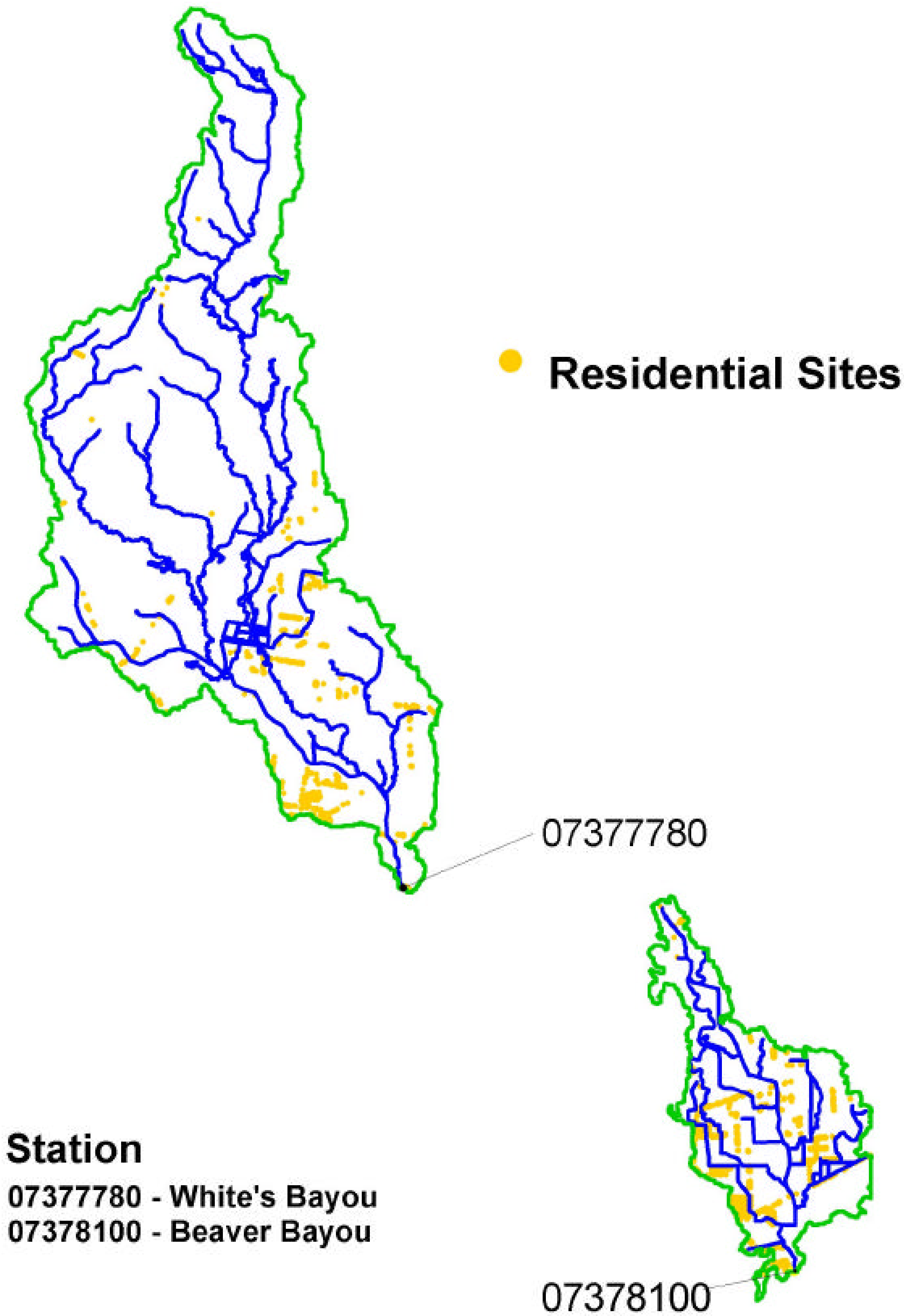

Figure A-5: Rural Watershed's Residential Sites Data Layer.

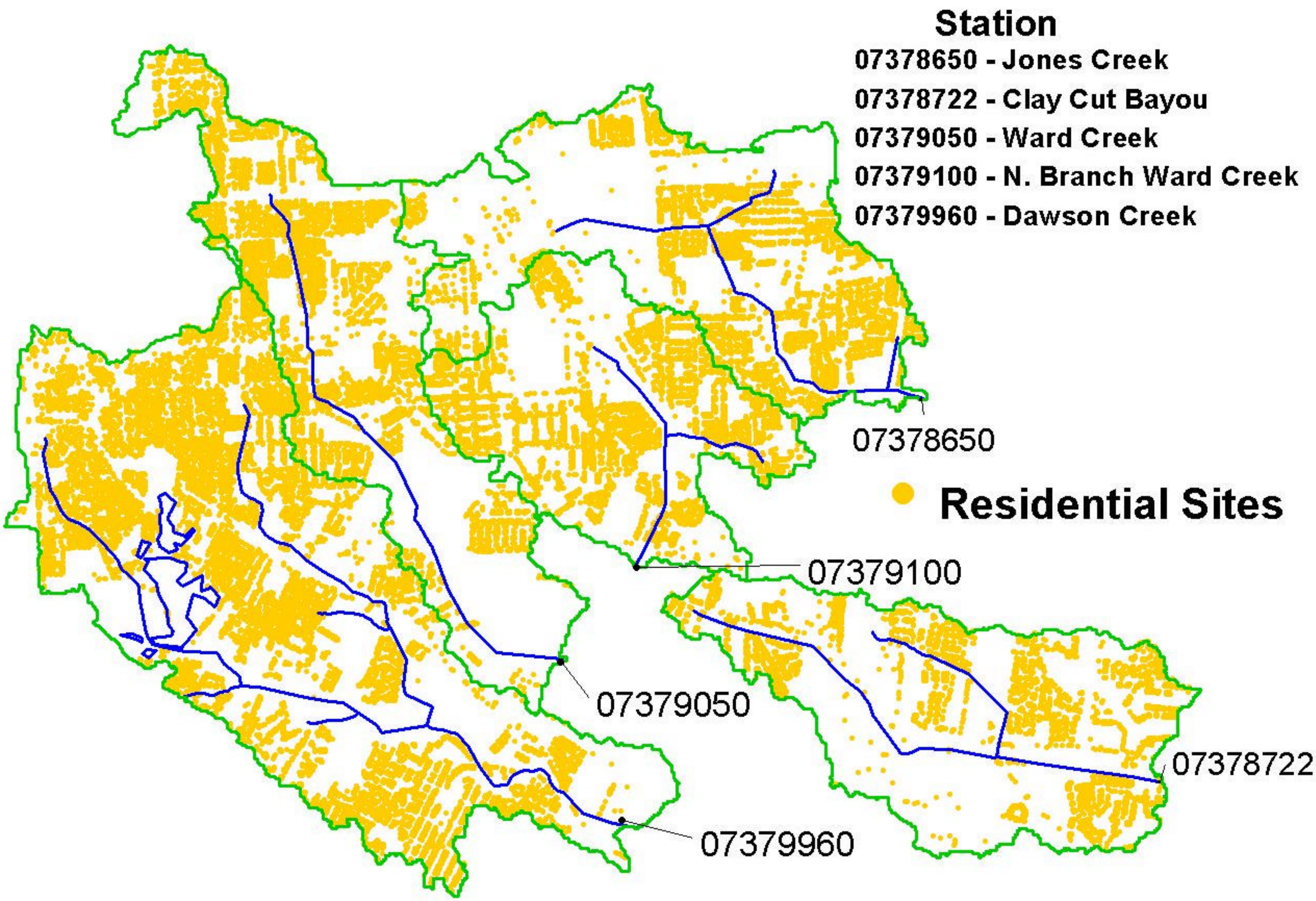

Figure A-6: Urban Watershed's Residential Data Layer.

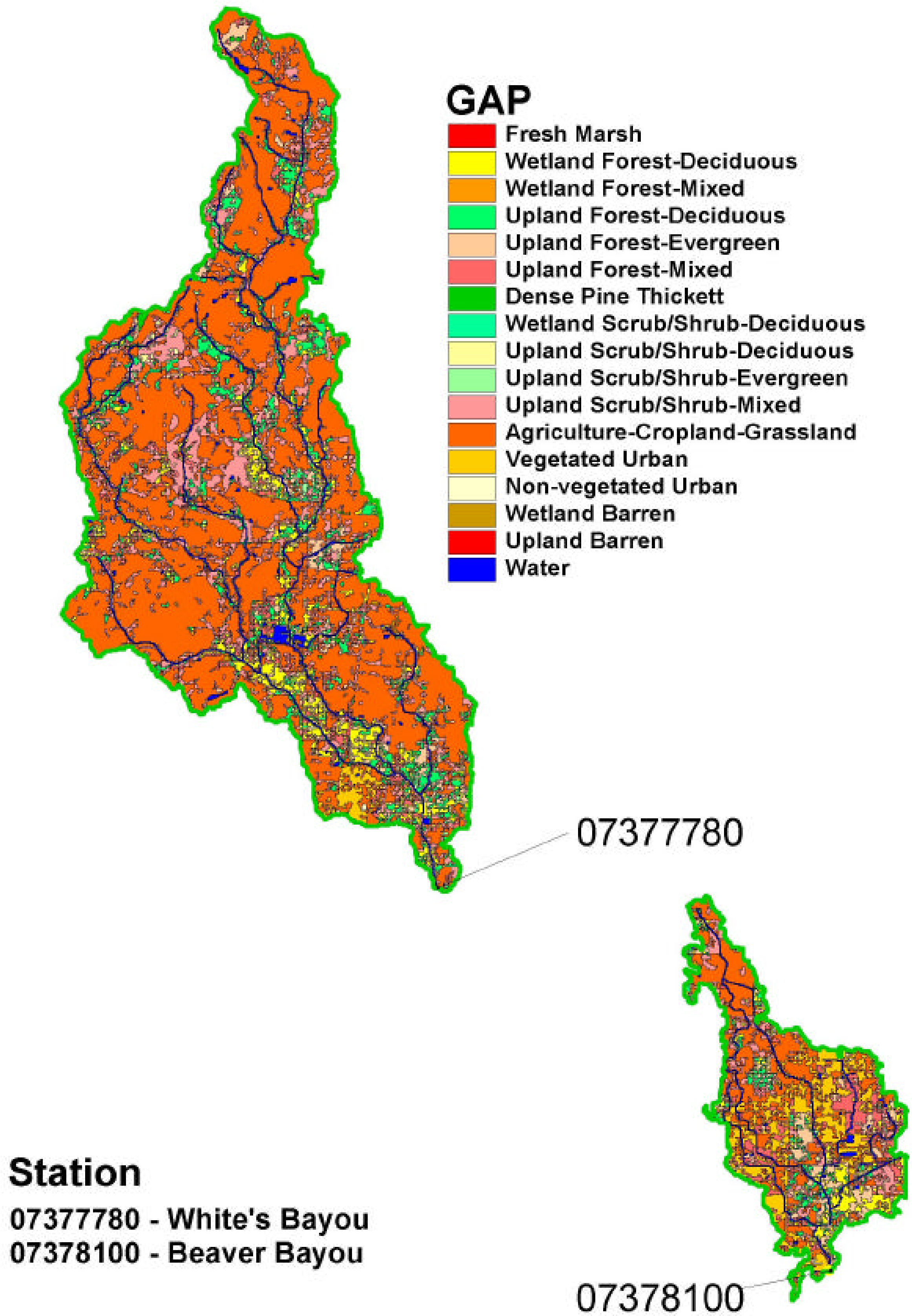

Figure A-7: Rural Watershed's GAP Data Layer.

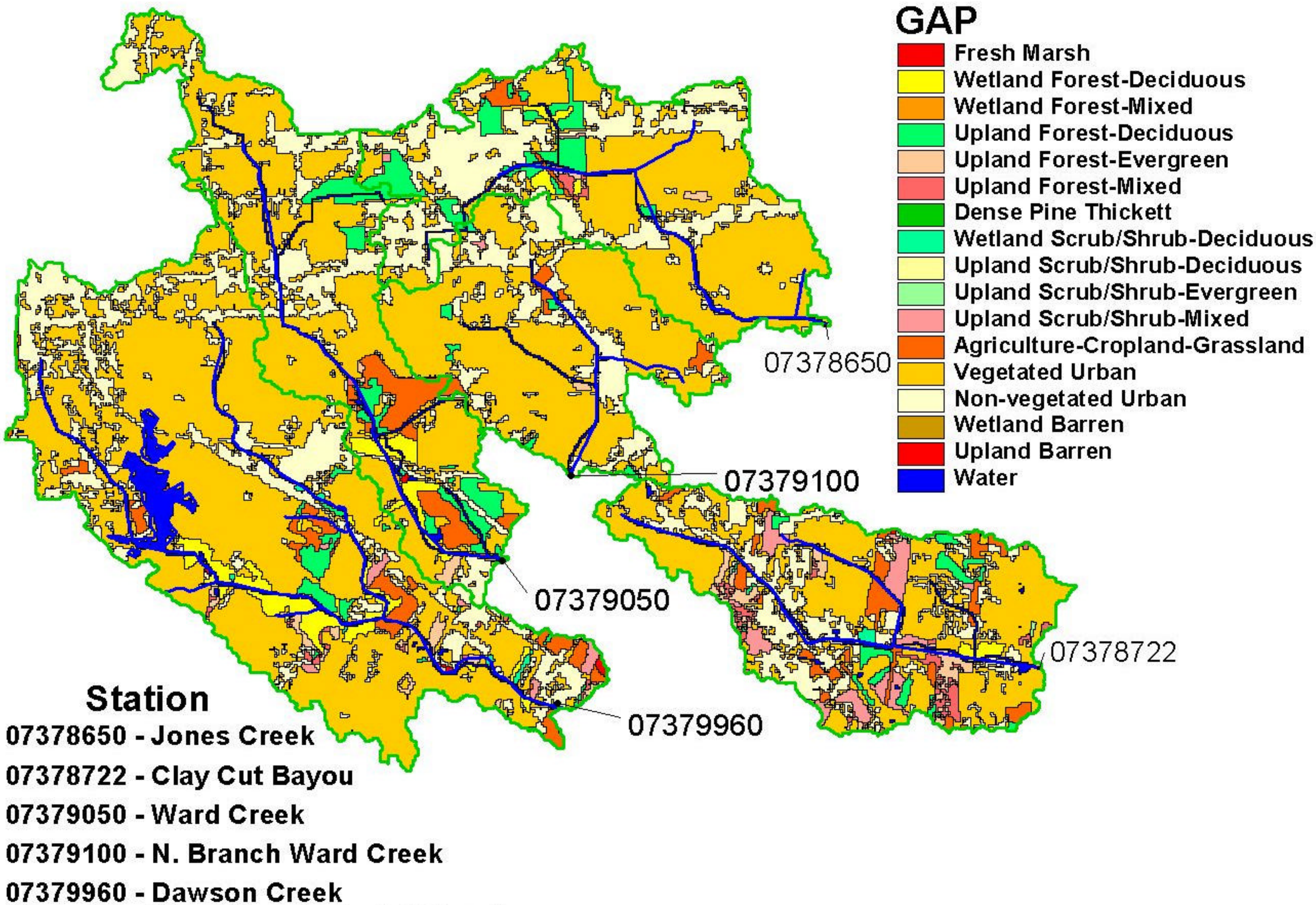

Figure A-8: Urban Watershed's GAP Data Layer.

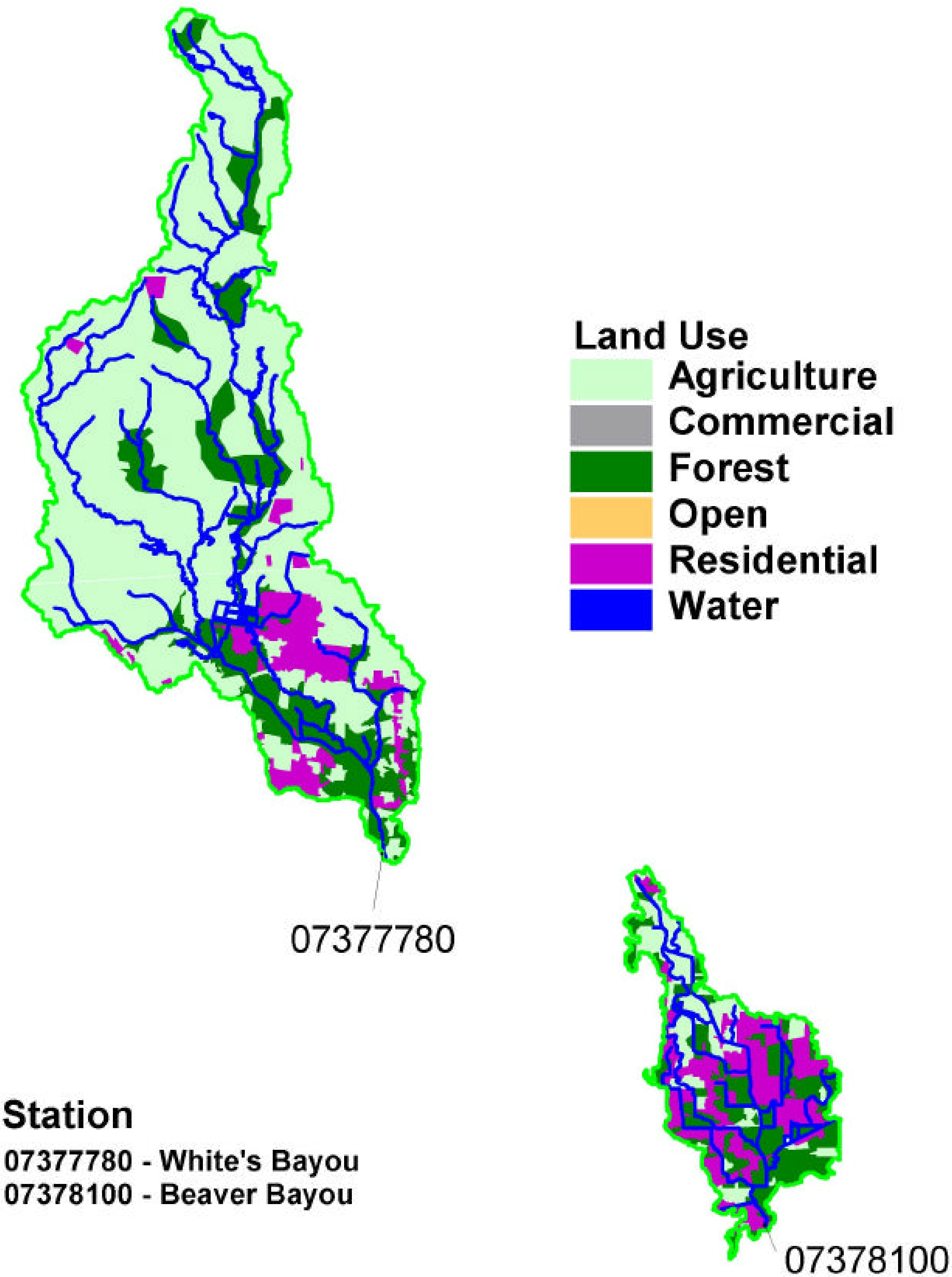

Figure A-9: Rural Watershed's Land Use Data Layer.

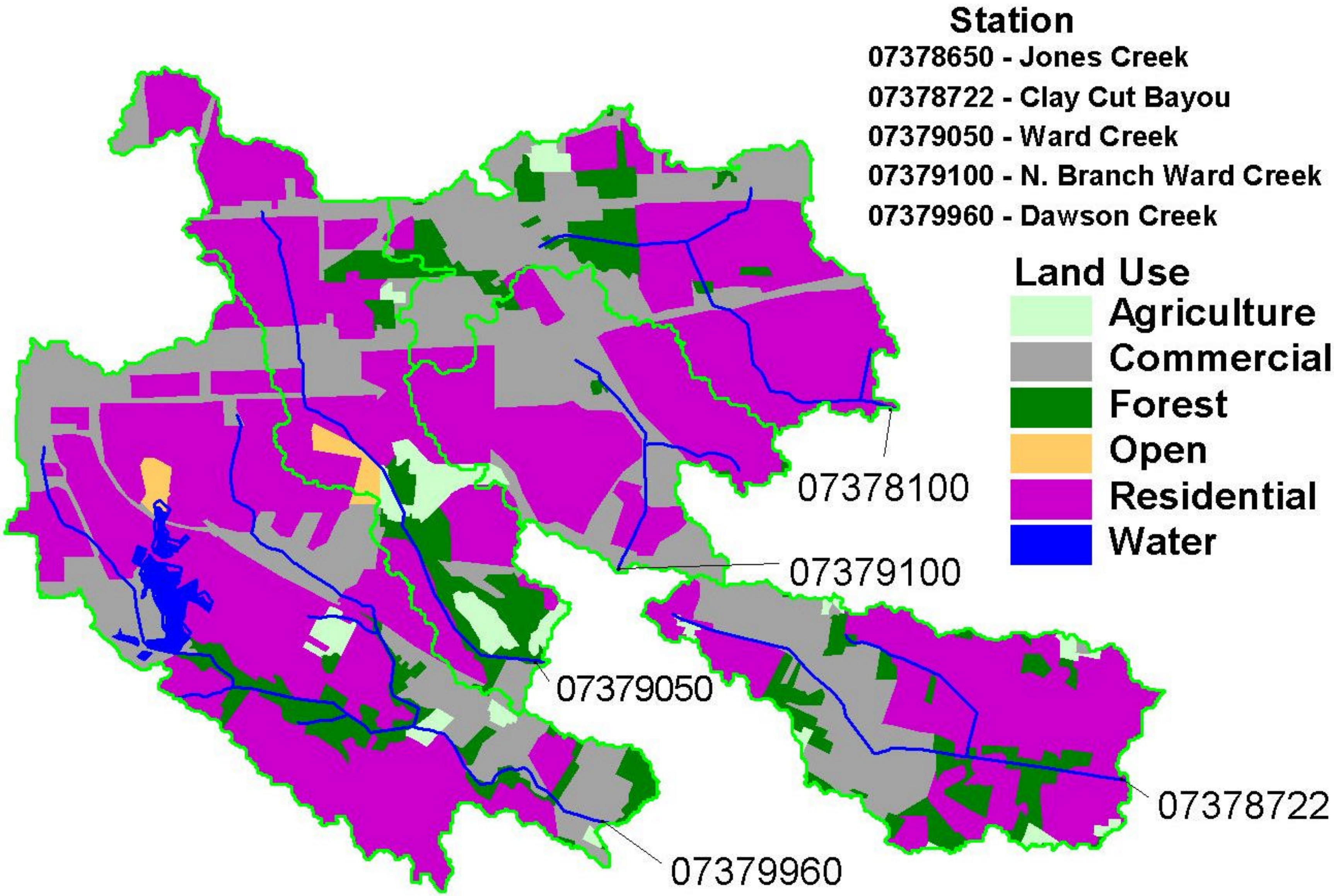

Figure A-10: Urban Watershed's Land Use Data Layer.

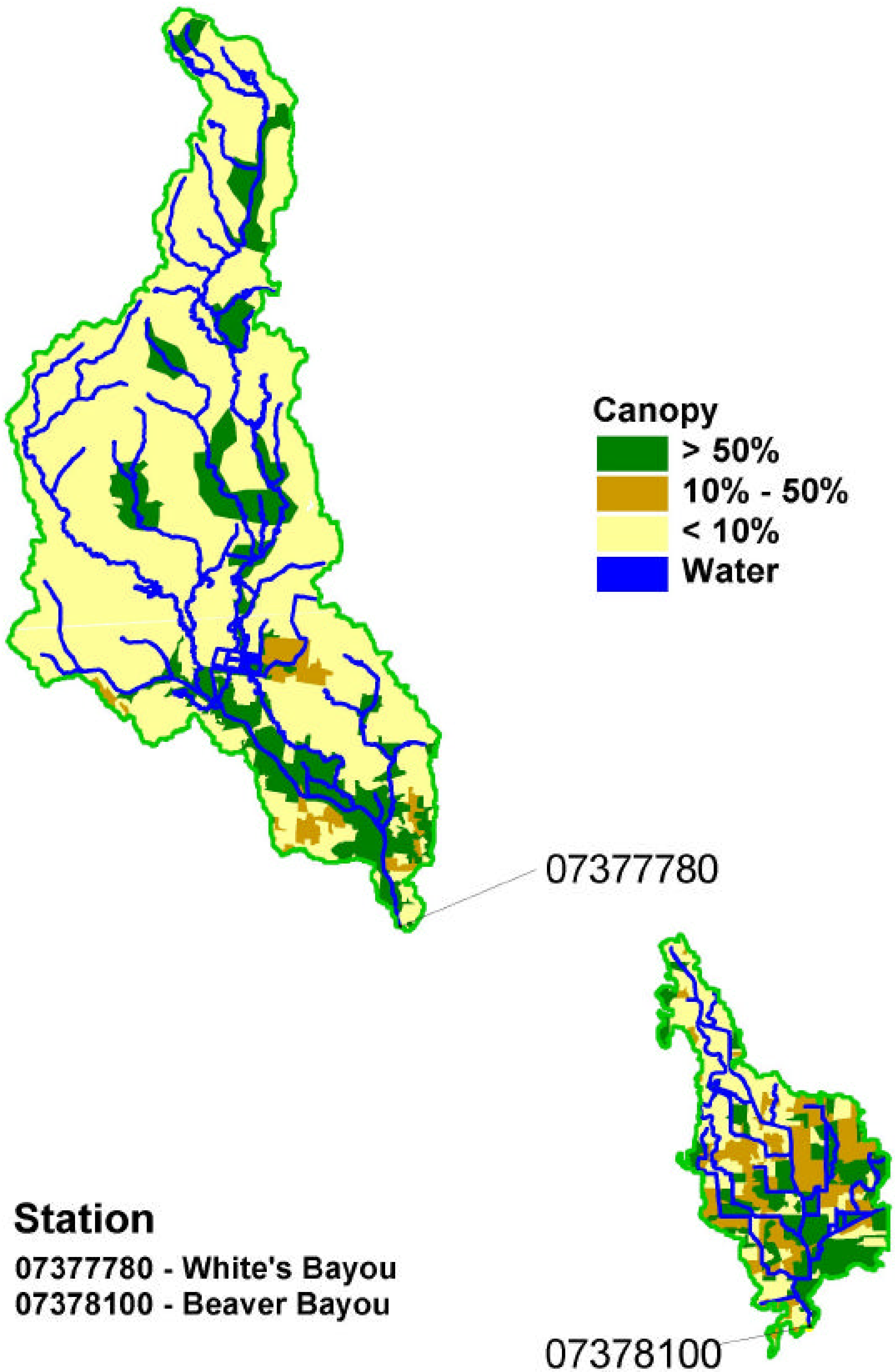

Figure A-11: Rural Watershed's Canopy Data Layer.

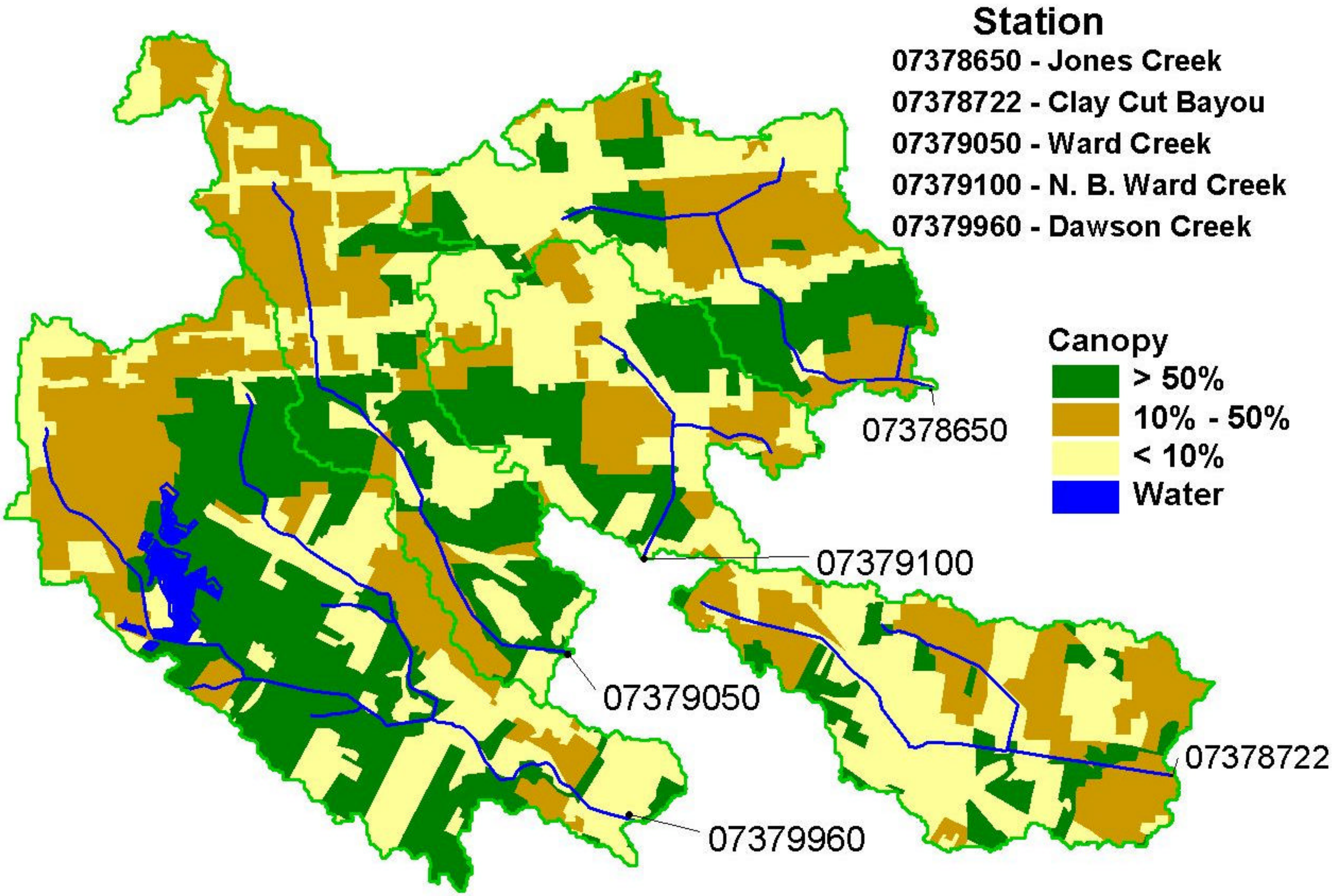

Figure A-12: Urban watershed's Canopy Data Layer.

Appendix B: Land Use and Land Cover Data

Watershed Land Use and Land Cover Data

Station Number	Station Name	Watershed Area	Number of commercial Sites	Commercial Density	Number of Residential Sites
7378100	Beaver Bayou	10.272	45	4.38084	1273
7378722	Claycut Bayou	8.025	1641	204.49617	6904
7379960	Dawson Creek	15.621	8598	550.41291	24963
7378650	Jones Creek	8.550	2572	300.80464	7182
7379100	N. Branch Ward Creek	6.391	2375	371.61052	6417
7379050	Ward Creek at Essen	8.419	2420	287.44506	7974
7377780	Beaver Bayou	44.438	335	7.53859	2105

Station Number	Residential Density	Road Length (mi)	Road Density	Area of Forest Canopy (mi^2)	Percentage of Forest Canopy
7378100	123.92913	40.73536	3.96567	3.351756	32.6
7378722	860.35441	81.88800	10.20462	1.182464	14.7
7379960	1598.04110	248.8851	15.93273	6.048640	38.7
7378650	839.96070	97.43006	11.39480	2.198427	25.7
7379100	1004.05251	83.15003	13.01028	2.033454	31.8
7379050	947.14337	113.4818	13.47926	2.459235	29.2
7377780	47.36937	95.08990	2.13983	8.286057	18.6

Station Number	Percentage of Forest Canopy	Area of Transition Canopy (mi^2)	Percentage of Transition Canopy	Area of Open Canopy (mi^2)
7378100	32.6	2.855975	44.7	4.064428
7378722	14.7	3.000753	37.4	3.841376
7379960	38.7	4.376990	28.0	4.809967
7378650	25.7	2.698668	31.6	3.653251
7379100	31.8	1.605574	25.1	2.752013
7379050	29.2	3.176849	37.7	2.782464
7377780	18.6	1.140244	2.6	34.951887

Station Number	Percentage of Open Canopy	Area of Agriculture Land use (mi^2)	Percentage of Agriculture Land Use	Area of Forest Land Use (mi^2)
7378100	39.6	2.606563179	25.38	3.909363757
7378722	47.9	0.221134187	2.76	1.213549151
7379960	30.8	0.292252729	1.87	1.252461895
7378650	42.7	0.102005562	1.19	0.998263435
7379100	43.1	0.052144499	0.82	0.053999529
7379050	33.0	0.70064081	8.32	1.190667488
7377780	78.7	32.79512709	73.8	8.421363749

Station Number	Percentage of Forest Land Use	Area of Residential Land Use (mi^2)	Percentage of Residential Land Use	Area of Commercial land Use (mi^2)
7378100	38.07	3.756232935	36.57	0
7378722	15.61	4.396906024	54.79	2.193003443
7379960	8.02	9.057652093	57.98	4.475789767
7378650	11.68	4.300297412	50.3	3.149779174
7379100	0.84	3.877802408	60.68	2.40709461
7379050	14.14	4.619888236	54.87	1.727989436
7377780	18.95	3.152822845	7.09	0.179363063

Station Number	Percentage of Commercial Land Use	Area of GAP Non-Vegetated Urban (mi^2)	Percentage of GAP Non-Vegetated Urban	Area of GAP Vegetated Urban (mi^2)
7378100	0	0.010070091	0.10	2.032474139
7378722	27.33	1.766621258	22.02	4.127859359
7379960	28.65	3.17027851	20.29	9.876923696
7378650	36.84	2.793074667	32.67	4.648204773
7379100	37.66	1.457839051	22.81	4.552632913
7379050	20.52	1.815371	21.56	4.820881
7377780	0.4	0.016949441	0.04	0.408568152

Station Number	Percentage of GAP Vegetated Urban	Area of GAP Upland Forest Deciduous (mi^2)	Percentage of GAP Upland Forest Deciduous	Area of Gap Upland Forest Evergreen (mi^2)
7378100	19.79	0.443792	4.32	1.056621355
7378722	51.44	0.270124	3.37	0.288567503
7379960	63.23	0.264289	1.69	0.187353089
7378650	54.36	0.626771	7.33	0.051529278
7379100	71.23	0.074499	1.17	0.017697028
7379050	57.26	0.582441	6.92	0.055397
7377780	0.92	3.004896	6.76	2.023333189

Station Number	Percentage of GAP Upland Forest Evergreen	Area of GAP Upland Forest Mixed (mi^2)	Percentage of GAP Upland Forest Mixed	Area of GAP Upland Mixed Scrub Shrub (mi^2)
7378100	10.29	1.146612422	11.16	0.943706
7378722	3.60	0.235867889	2.94	0.047786
7379960	1.20	0.070571289	0.45	0.130578
7378650	0.60	0.046911186	0.55	0.017624
7379100	0.28	0.005899371	0.09	0.010077
7379050	0.66	0.004517	0.05	0
7377780	4.55	1.951212991	4.39	6.569429

Station Number	Percentage of GAP Upland Mixed Scrub Shrub (mi^2)	Area of GAP Agriculture (mi^2)	Percentage of Gap Agriculture
7378100	9.19	3.150104	30.67
7378722	0.60	0.51855	6.46
7379960	0.84	0.555121	3.55
7378650	0.21	0.104954	1.23
7379100	0.16	0.151559	2.37
7379050	0.00	0.587447	6.98
7377780	14.78	25.20383	56.72

Vita

Josey Wade Walker was born in Hattiesburg, Mississippi, on November 14, 1977. His love of the environment led him to study environmental biology. He obtained his bachelor of science degree from the University of Southern Mississippi in 2000. He then enrolled directly into the Department of Environmental Studies to pursue his master of science degree.